ELEMENTS OF
STEAM AND GAS POWER ENGINEERING

McGraw-Hill Book Co. Inc.
PUBLISHERS OF BOOKS FOR
Electrical World ▿ Engineering News-Record
Power ▿ Engineering and Mining Journal-Press
Chemical and Metallurgical Engineering
Electric Railway Journal ▿ Coal Age
American Machinist ▿ Ingenieria Internacional
Electrical Merchandising ▿ Bus Transportation
Journal of Electricity and Western Industry
Industrial Engineer

ELEMENTS OF
STEAM AND GAS POWER ENGINEERING

BY

ANDREY A. POTTER
DEAN OF ENGINEERING, PURDUE UNIVERSITY, FORMERLY DEAN OF ENGINEERING,
KANSAS STATE AGRICULTURAL COLLEGE. AUTHOR OF "FARM MOTORS",
ENGINEERING THERMODYNAMICS, ETC.

AND

JAMES P. CALDERWOOD
PROFESSOR OF MECHANICAL ENGINEERING IN THE KANSAS STATE AGRICULTURAL
COLLEGE. AUTHOR OF ENGINEERING THERMODYNAMICS, ETC.

FIRST EDITION
FOURTH IMPRESSION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1920

THE MAPLE PRESS YORK PA

PREFACE

In the preparation of this treatise the authors have attempted to present a clear and concrete statement of the principles underlying the construction and operation of steam and gas power equipment.

The first chapter is devoted to a general survey of the field of power engineering and brings out the factors essential for the production of power, the principles governing the action of various mechanical motors, and a comparison of their performance.

The main portion of the book is divided into three parts. The first part takes up the subject of steam power and includes fuels, combustion, theory of steam generation, boilers, boiler auxiliaries, boiler accessories, steam engines, steam turbines, auxiliaries for steam engines and turbines, and the testing of steam power equipment. The second part is devoted to gas power and includes a study of the internal combustion engine, fuels for internal combustion engines, gas producers and the various auxiliaries found in connection with internal combustion engine power plants. The last portion of the book treats of the application of steam and gas power to locomotives, automobiles, trucks and tractors.

The method followed in each chapter was to give: first, the fundamental principles underlying the particular phase of equipment under consideration; second, the structural details; third, auxiliary parts; fourth, operation and management of the equipment considered.

This book has been prepared primarily as a textbook for students in engineering schools and colleges in order to familiarize them with power plant equipment before they take up the more abstract study of thermodynamics and design. The subject matter of this treatise is so prepared that it should prove of considerable value to those who are responsible for the operation of steam or internal combustion engine power plants. Illustrative problems will be found at the close of each chapter. These problems are intended mainly as a guide in encouraging outside reference reading.

In the preparation of this text the authors are particularly indebted to H. W. Davis and A. J. Mack of the Kansas State Agricultural College for their valuable assistance.

The authors are also grateful to E. M. Shealy, J. A. Moyer, A. J. Wood, C. F. Gebhardt, L. H. Morrison, R. H. Fernald, G. A. Orrok, and A. M. Greene for their permission to use certain illustrations from publications of which they are authors. The various manufacturers of power machinery have also been most liberal in giving the authors permission to use cuts.

ANDREY A. POTTER.
JAMES P. CALDERWOOD.

MANHATTAN, KANSAS,
January, 1920.

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER XIII

CHAPTER XIV

CHAPTER XV

ELEMENTS OF STEAM
AND
GAS POWER ENGINEERING

CHAPTER I

FUNDAMENTALS OF POWER ENGINEERING

Mechanical Power.—The substitution of mechanical power for animal labor marks a most important epoch in the progress of civilization. The increase in the amount of mechanical power used for manufacturing, for transportation, and for other purposes has been enormous during the past forty years and particularly so in the United States of America. The greatest factors which contributed to the increased use of power are the development of electrical machinery and efficient electrical transmission systems, the perfection of the internal combustion engine and steam turbine, the growth of the manufacturing industries, and the improvements in transportation equipment and systems.

Factors Essential for the Production of Power.—Two requirements are essential for the production of power: first, a source from which energy may be derived; and second, a motor which is capable of transforming this energy into work. Without energy all attempts to produce power would be futile; without a motor energy cannot be utilized, even when available, in producing power.

A motor is an apparatus capable of transforming energy into mechanical work. Any apparatus which transforms energy from one form into another, but not into work, is not a motor.

A Motor Must Do Work. By work is meant the production of motion against some external force. The mechanical motors available for the production of power are heat engines, including steam, gas, oil, hot-air, and solar engines; pressure engines, such as water wheels and water motors; windmills; electric motors.

Sources of Energy.—The principal source of all energy is the sun. It causes the growth of plants which furnish food for man and animals. The great coal deposits are only the result of the storing up of the sun's rays in plants in bygone days. These rays are also responsible for the raising of water from sea level to mountain top, thus giving it energy which can be utilized to turn water wheels and do useful work.

On the other hand, while the sun's rays are the fundamental source of all energy, they can be utilized directly by man only to a very limited extent. Heat engines have been built which transform the heat derived directly from the sun into mechanical energy; but, because of their bulk when compared with the energy transformed and because of the irregularities in the sun's rays caused by clouds and the movement of the earth, this type of motor has never proved practicable. As a result, secondary sources of energy must be utilized. These secondary sources are: the wind; waterfalls; carbon in different forms, such as coal, petroleum, or gas; and chemicals such as are used in electric batteries.

Principles Governing the Action of Various Mechanical Motors.—All mechanical motors do work by virtue of motion given to a piston, or to blades on a wheel by some substance such as water, steam, gas, or air; or to a rotor by electricity. The first requirement in any of these cases is that the above-mentioned substance, often called the working substance, be under considerable pressure.

This pressure in the case of the water motor or waterwheel is obtained by collecting water in dams and tanks, or by utilizing the kinetic energy of natural waterfalls. The total power available in water when in motion depends on the weight of water discharged in a given time and on the head or distance through which the water is allowed to fall. The head of water can be utilized by its weight or pressure acting directly either on a piston, or on blades or paddles on wheels.

Considering next the various forms of heat engines, we find work accomplished by steam or gas under pressure, the pressure being obtained by utilizing the heat of some fuel or of the rays of the sun.

A motor utilizing the heat of the sun is called a solar motor or a solar engine. The action of this type of motor depends on the vaporization of water into steam by means of the rays of the sun, which are concentrated and intensified by means of reflecting surfaces. The steam thus generated is used in some form of heat motor.

In the case of the steam power plant (Fig. 1, page 6) a fuel, like coal, oil, or gas, is burned in a furnace and its heat of combustion is utilized in changing water into steam at high pressure in a special vessel called a boiler. This high-pressure steam is then conveyed by pipes to the engine cylinder where its energy is expended in pushing a piston as in the case of the reciprocating engine. The sliding motion of the piston may be changed into rotary motion at the shaft by the interposition of a connecting rod and crank. Another method is to allow the high-pressure steam to escape through a nozzle, strike blades on a wheel and produce rotary motion direct, as in the case of the steam turbine (Fig. 109, page 135).

In another type of heat engine, called a hot-air engine, air is heated in the engine cylinder by a fuel which is burned outside of the cylinder. The air by its expansion drives a piston and does work.

In the case of gas and oil engines (Fig. 163, page 194), the fuel which must be in a gaseous form as it enters the engine cylinder, is mixed with air in the proper proportions to form an explosive mixture. It is then compressed and ignited within the cylinder of the engine, the high pressure produced by the explosion pushing on a piston and doing work. These engines belong to a class called internal-combustion engines, and differ from the steam and hot-air engines, which are sometimes called external-combustion engines, in that the fuel is burned inside the engine cylinder, instead of in an auxiliary apparatus.

The windmill derives its high pressure for doing work from the moving atmosphere.

The electric motor converts electrical energy at high pressure into work; this electrical pressure or voltage is produced in an apparatus called an electrical dynamo, or a generator of electricity.

Comparison of Various Types of Motors.—The solar motor, as previously stated, is but little used on account of its high first cost and great bulk in relation to the small power developed.

In localities where the wind is abundant and little power is needed, the windmill is a desirable and cheap source of power. The greatest application of windmills is for the pumping of water for residences and farms, and for such other work as does not suffer from suspension during calm weather. Electric storage and lighting on a small scale from the power of a windmill has been tried in several places with fair success, but probably will not be adopted to any great extent on account of the high first cost and the small practical capacity of such an installation.

The water motor or water turbine is very economical if a plentiful supply of water can be had at a fairly high head, but its reliability is affected by drought, floods, and ice in the water supply. For this reason many of the hydraulic power stations must resort to the use of steam or gas power during certain seasons of the year.

The hot-air engine, while not economical in fuel consumption, is used to a limited extent for pumping water in places where the cost of fuel is not an important item and where safety and simplicity of mechanism are essential. The hot-air engine, on account of its high cost, bulk, and poor fuel economy, has been largely superseded by the oil engine, which uses gasoline or the heavier oils.

The internal-combustion engine (Chapter XI), whether using gas or oil, is well adapted for small and medium-sized powers. It finds its greatest application in the automobile and in other power vehicles (Chapter XVI); also for uses on farms either as stationary engines or as oil traction engines.

For the generation of electricity, especially in large units, the steam engine (Chapter VII) and the steam turbine (Chapter VIII) have been found to be the most suitable types of motors, because of their lower first cost, when compared with other types of motors, and because of their greater reliability. By far the greatest part of commercial power is developed by steam motors. The reason for this fact is that the conversion of power from one form into another is always accompanied by losses; thus power developed from a cheap source is not necessarily the most economical from a commercial point of view. An example of this is the hydro-electric plant, where the cost of power would be small if no consideration had to be taken of the greater first cost of the installation and the cost of the long transmission lines. As another illustration, the oil engine is conceded to have the highest efficiency as a motor for the transforming of heat energy into work, but commercially its application has been limited to special uses or to those localities in which the cost of oil is low and the supply is large. When all factors are considered, it is usually found that the steam power plant is the cheapest producer of power in large quantities.

About three-fourths of the total power used for manufacturing in this country is developed by steam prime movers; that is by steam engines and steam turbines. In electric generating stations over 70 per cent. of the power is developed by steam prime movers and but slightly more than 1 per cent. by internal combustion engines. The power developed by gas and oil engines in connection with the manufacturing industries is less than 5 per cent.

Principal Parts of a Steam Power Plant.—The principal parts of a simple steam power plant are illustrated in Fig. 1, and include the following:

1. A furnace, in which the fuel is burned. This consists of a chamber arranged with a grate (1), if coal or any other solid fuel is used, and with burners when the fuel is in the liquid or gaseous state. The furnace is connected through a flue or breeching (2) to a chimney. The function of a chimney is to produce sufficient draft, so that the fuel will have the proper amount of air for combustion; it also serves to carry off the obnoxious gases after the combustion process is completed. The flue leading to the chimney is provided with a damper (3), so that the intensity of the draft can be regulated.

2. A boiler (4), which is a closed metallic vessel filled to about two-thirds of its volume with water. The heat developed by the burning of the fuel in the furnace is utilized in converting the water contained in the boiler into steam. The boiler (4) is arranged with a water column (5) to show the water level, with

a safety valve (6) to prevent the pressure from rising too high, and with a gage (7) to indicate the steam pressure.

3. The function of a setting, which is the term usually used to designate the brick work which surrounds the boiler, is to provide correct spaces for the furnace, combustion chamber and ash-pit, to prevent air from entering the furnace above the fuel bed, and to decrease the heat of radiation to a minimum. In some power plants the setting is also used to support the boiler shell, but this is poor practice.

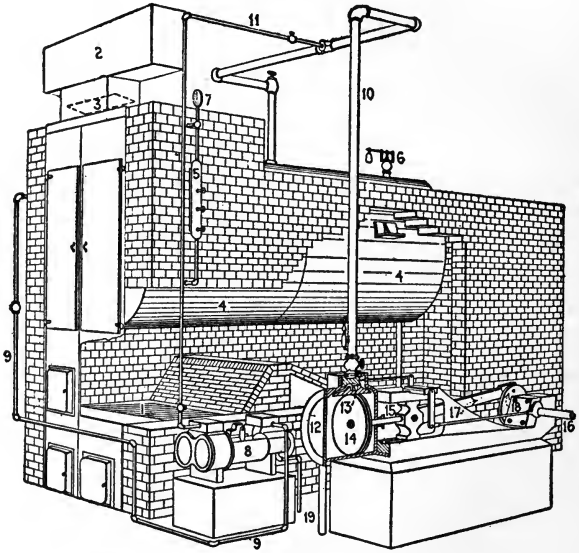


Fig. 1.—Elementary non-condensing power plant.

4. The feed pump (8) supplies the boiler with water through the feed pipe (9).

5. The steam lines (10) and (11) convey steam from the boiler to the engine and to the steam end of the pump respectively.

6. In the engine the energy of the steam is expended in doing work. The steam enters the engine cylinder (12) through the valve (13) and pushes on the piston (14). The sliding motion of the piston, which is transmitted to the piston rod (15), is changed into rotary motion at the shaft (16) by means of a connecting rod (17) and crank (18).

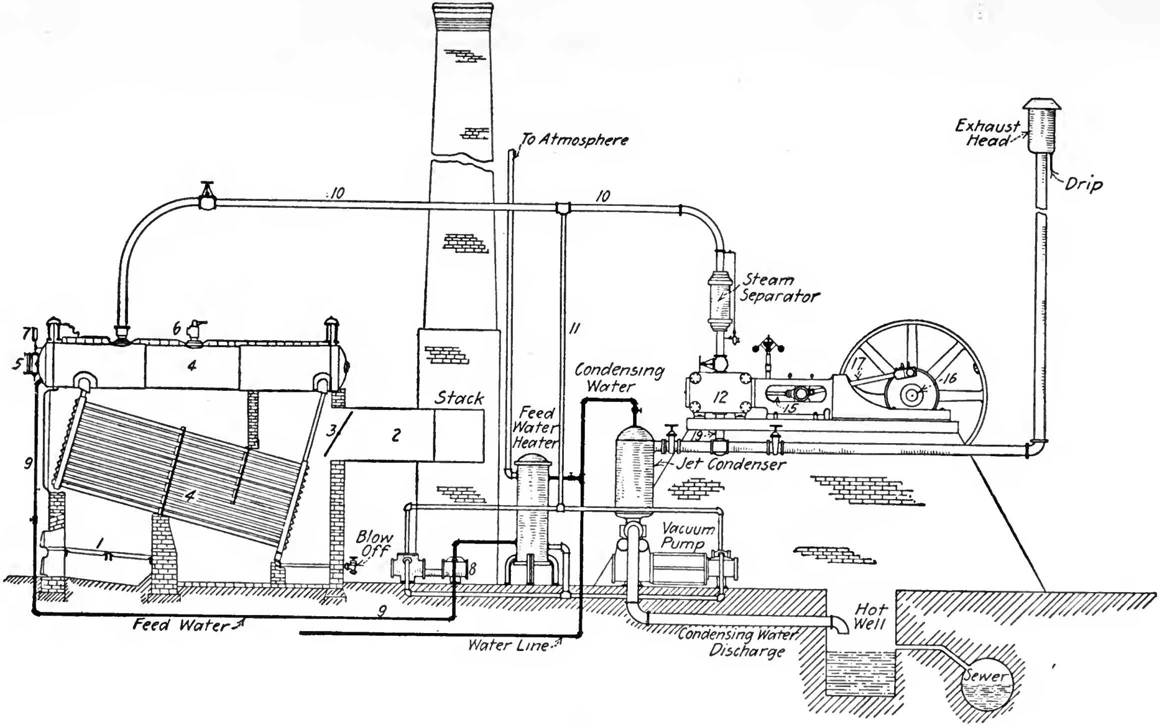


Fig. 2.—Condensing steam power plant.

7. The exhaust pipe (19) conveys the used steam to the atmosphere, or to some use where its heat is abstracted, converting the steam back into water.

Condensing Steam Power Plant.—In Fig. 2 is illustrated a condensing steam power plant with water tube boilers. The various parts are numbered to correspond with similar parts in the simple power plant of Fig. 1.

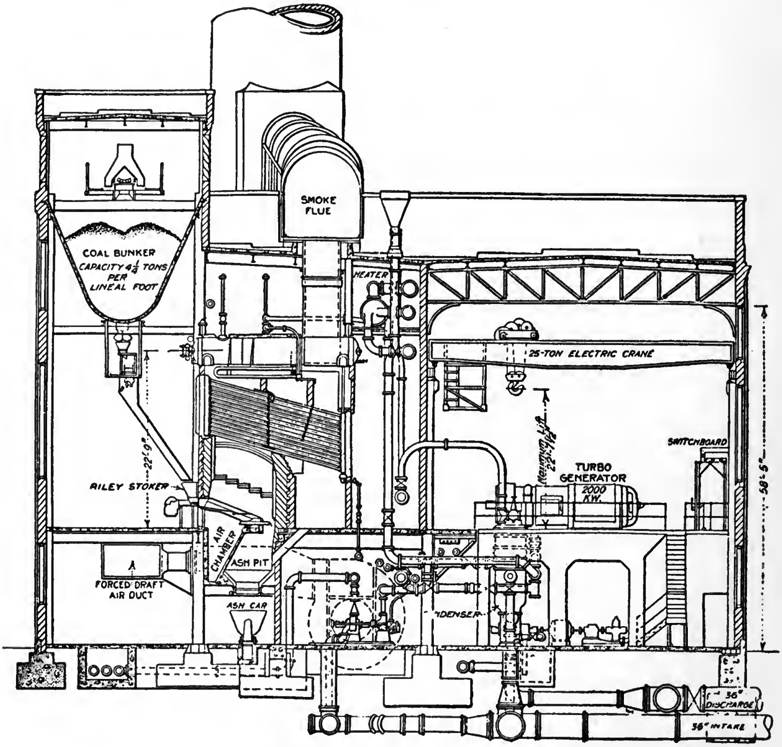


Fig. 3.—Modern steam power plant.

In Fig. 3 is illustrated a modern steam turbine plant equipped with coal and ash handling machinery, mechanical stokers, and other labor saving devices.

Gas Power Plants.—The equipment of a gas power plant depends upon the fuel used. The simplest type of gas power plant is the gasoline engine (Fig. 163), which consists of a cylinder and piston, a carburetor for preparing the explosive mixture, valves for admitting the mixture to the cylinder and for expelling the burnt gases to the atmosphere, a device for igniting the mixture at the proper time, a mechanism for changing the reciprocating motion of the piston into rotary motion, a governor to keep the speed constant at variable loads, a lubrication system for the cylinder and bearings, an arrangement for cooling the cylinder walls, a flywheel to carry the engine through the idle strokes, and bearings and a frame to support the various parts.

Details concerning various types of gas power plants will be given in Chapter XI.

Problems

1. Make a thorough study of some non-condensing steam power plant in your vicinity and hand in a report concerning the important details. State in which respects the power plant you have examined differs from that illustrated in Fig. 1.

2. Make a sketch showing how the piping in a non-condensing power plant would be modified if the exhaust steam is used for heating.

3. Make a study of some internal combustion engine power plant and hand in a report concerning fuel used and fundamental details of the engine.

CHAPTER II

STEAM POWER FUELS AND COMBUSTION

FUELS

The fuel in the case of the steam power plant is burned under the boiler, and its heat is utilized in changing water into steam.

Fuels may be used in their natural state, or may be prepared or manufactured in various ways. The chief natural fuels are coal, wood, petroleum oil, and natural gas. The chief prepared fuels are coke made from the distillation of coal, artificial gas made from solid or liquid fuels, and the various petroleum distillates. Another prepared fuel is briqueted coal which is made by pressing finely ground coal into brick form, the particles being held together by some cementing material. There are a great many other materials which could be used for fuel, such as acetylene, alcohol, and benzol, that have valuable fuel properties, but their high cost makes their use prohibitive. Then again there is another class of fuel which is derived as a by-product in various industries. To this class belongs gas discharged from blast furnaces which has considerable value as a fuel.

The Heating Value of Fuels.—By the heating value of a fuel, often expressed by the terms, heat of combustion, calorific value, and heat content, is meant the amount of heat liberated by the perfect combustion of one unit weight of a solid or liquid fuel, or of a unit volume of a gaseous fuel. The value of the fuel for power purposes is dependent upon its heat content in a unit weight. Thus of two grades of coal, the one containing the greater heating value is the most desirable commercially, other things being equal.

The heating value of the fuel is measured in heat units. A heat unit is the amount of heat required to raise the temperature of one pound of water one degree. The unit used in English speaking countries is the British thermal unit (B.t.u). The B.t.u. is defined as the amount of heat required to raise the temperature of one pound of water from 62 to 63 degrees Fahrenheit. Another definition of a B.t.u. is $\frac{1}{180}$ of the heat required to raise the temperature of one pound of water from the freezing point to the boiling point on the Fahrenheit scale.

This calorific value or the heating value of a fuel may be determined by means of a chemical analysis, but a more satisfactory determination can be made by an instrument, called a coal calorimeter.

Several different types of coal calorimeters are available, but those of the bomb type, similar to the one illustrated in Fig. 4, are the most accurate and satisfactory for determining the heating value of solid and heavy liquid fuels. This type of instrument consists of a steel vessel or bomb, lined with porcelain, platinum, or gold to prevent corrosion, and into which a weighed sample of the fuel is introduced. The bomb, after it has been charged with fuel, is filled with oxygen from the cylinder *O*, to which the bomb is connected through the union *U*. The quantity of oxygen admitted to the bomb is regulated by means of the valve *W* and the pressure gage *M*. The bomb is then placed in the calorimeter vessel *A*, which contains a known weight

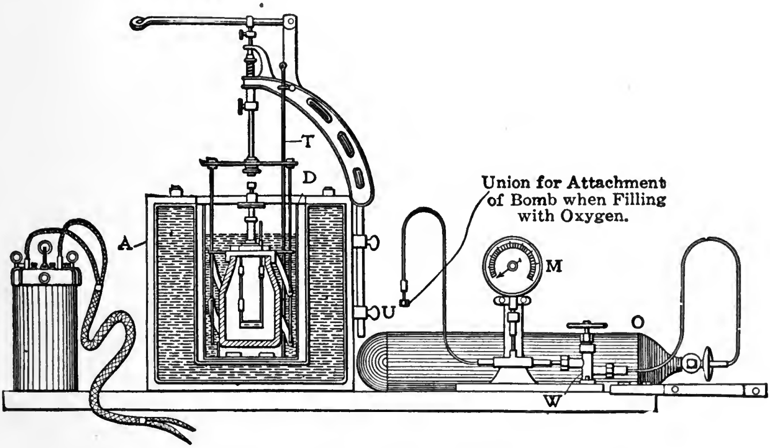


FIG. 4.—Bomb calorimeter.

of water. The water is agitated by the stirring mechanism shown and the thermometer T indicates its rise in temperature when the fuel within the bomb is burned. The calorimeter vessel A is fitted with a water jacket which reduces the effect of external changes of temperature and causes a more uniform temperature of the thermometer T. The fuel charge is ignited electrically and burns in the presence of oxygen. The heating value of the fuel is calculated from the observed temperature rise of the water as indicated by thermometer T, since the heat gained by the water must equal the heat given up by the fuel, after making allowances for radiation and other similar factors which may produce a gain or loss of heat.

The Proximate Analysis of Fuels.—While the heating value of a fuel is important in estimating its commercial value, other properties must be considered as well. Two different coals, for instance, may have the same heating value but the properties of one, not disclosed by the heating value, may cause it to be more or less desirable than the other coal. The proximate analysis of a fuel has been devised to assist in this. The proximate analysis determines the amount of moisture, volatile matter, fixed carbon, ash and sulphur.

Moisture requires heat for its evaporation, and is direct loss. Ash, when present in large amounts, will form clinkers, and is also an item of expense in its disposal. Sulphur is usually considered a detrimental constituent, especially if in amounts greater than 2 per cent. Coals containing large quantities of sulphur are usually avoided.

The volatile matter and the fixed carbon are the heat producing constituents of the coal. The volatile matter represents that part which distils off at a comparatively low temperature, and may be considered the gaseous or flaming constituent. The amount of volatile matter gives some conception of the smoke producing qualities of the fuel. If smokeless combustion must be secured in any particular plant, and no special furnaces have been installed which will insure the proper combustion of volatile gases, a coal with a large content of volatile matter should not be selected. The fixed carbon is just the reverse of the volatile matter; it being that part of the coal which burns without flame and consequently gives no trouble from smoke.

Fuels for Steam Generation.—The fuels most commonly used for steam generation are coal, wood, petroleum oils, and natural gas.

Wood is but little used for steam generation except in remote places, where timber is plentiful, or in special cases where sawdust, shavings, and pieces of wood are by-products of manufacturing operations. Wood burns rapidly and with a bright flame, but does not evolve much heat. When first cut, wood contains 30 to 50 per cent. of moisture, which can be reduced by drying to about 15 per cent. One pound of dry wood is equal in heat-producing value to about ½ lb. of soft coal. It is important that wood be dry, as each 10 per cent. of moisture reduces its heat-producing value as a fuel by about 12 per cent. The chemical compositions and the calorific values of some of the more common woods are shown in Table 1.

TABLE 1.—ANALYSIS AND CALORIFIC VALUE OF DRY WOOD

Kind of wood	Carbon	Hydrogen	Nitrogen	Oxygen	Ash	B.t.u. per pound
Oak	50.16	6.02	0.09	43.36	0.37	8,316
Ash	49.18	6.27	0.07	43.91	0.57	8,480
Elm	48.99	6.20	0.06	44.25	0.50	8,510
Beech	49.06	6.11	0.09	44.17	0.57	8,591
Birch	48.88	6.06	0.10	44.67	0.29	8,586
Fir	50.36	5.92	0.05	43.39	0.28	9,063
Pine	50.31	6.20	0.04	43.08	0.37	9,153

Coal is more extensively used as a fuel for steam generation than any other substance. It is a substance which results from collections of vegetable matter, which has been gradually changed in physical and chemical composition until it finally became coal.

In the first stages of the transformation the material is classed as peat. In its next stage it is known as lignite or brown coal. Following this in the proper order of transformation are soft or bituminous coal, semi-bituminous, semi-anthracite, and finally anthracite or hard coal.

Table 2 gives the proximate analyses and the calorific values of American coals.

TABLE 2.—COMPOSITION AND CALORIFIC VALUE OF AMERICAN COALS
(U. S. Bureau of Mines)

State	Classification	Proximate analysis					B.t.u. per lb., dry coal
		Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	
Pennsylvania.....	Anthracite........	2.19	5.67	86.24	5.90	0.57	13,828
Pennsylvania.....	Anthracite........	3.43	6.79	78.25	11.53	0.46	12,782
Pennsylvania.....	Semi-anthracite....	5.48	7.53	81.00	11.47	....	13,547
Pennsylvania.....	Semi-bituminous...	2.72	16.70	75.38	5.20	0.55	14,521
West Virginia....	Semi-bituminous...	3.17	18.46	70.86	7.51	1.07	13,995
Colorado........	Bituminous........	10.27	38.25	44.99	6.49	0.42	11,416
Illinois..........	Bituminous........	7.12	34.55	50.68	7.65	2.23	12,481
Kansas..........	Bituminous........	11.10	35.51	40.69	12.70	3.99	11,065
Kentucky........	Bituminous........	4.83	33.71	57.73	3.73	0.82	13,842
Missouri.........	Bituminous........	5.87	30.98	51.67	11.48	5.00	12,339
Ohio............	Bituminous........	5.15	37.34	49.00	8.51	2.94	12,733
Oklahoma.......	Bituminous........	4.83	35.76	55.55	3.86	1.34	13,829
Pennsylvania.....	Bituminous........	3.48	35.15	55.45	5.92	1.18	13,700
West Virginia....	Bituminous........	3.36	22.50	68.86	5.28	0.52	14,369
Colorado........	Lignites...........	20.71	31.82	43.98	3.45	0.45	9,941
North Dakota....	Lignites...........	32.65	30.57	28.49	8.29	1.33	7,357
Wyoming........	Lignites...........	23.46	35.64	35.73	5.17	0.49	9,050

The weight of coal per cubic foot will vary from 43 to 58 pounds. An anthracite coal will have a greater weight than a bituminous coal; the higher the amount of fixed carbon in the coal, the greater is its weight.

Anthracite, commonly known as hard coal, is the highest grade of coal. It consists mainly of fixed carbon having little, and in some cases no, volatile matter. Some varieties approach graphite in their characteristics, and are burned with difficulty unless mixed with other coals. This coal is slow to ignite, burns with a short flame, and gives an intense fire free from smoke. As it is available for steaming purposes only in certain limited sections, its use is not common.

Semi-anthracite coal is softer and lighter than anthracite. It contains less carbon than anthracite coal, and its volatile matter ranges from 7 to 12 per cent. It ignites more readily than anthracite and makes an intense, free-burning fire.

Semi-bituminous coal has all the physical characteristics of bituminous coal, but it differs from it in that the volatile matter content is not so high. Semi-bituminous coal contains from 12 to 25 per cent. volatile matter, and when compared with semi-anthracite coal its fixed carbon is less.

Bituminous coal is a classification intended to include coals which contain 20 per cent. or more volatile matter and less than 60 per cent. of fixed carbon. One objection to the use of bituminous coal as a fuel is its smoking quality. This may be an undesirable feature, especially if its use is in a city where smoke ordinances are enforced and when special smokeless furnaces have not been installed. Another feature which may be considered undesirable is the tendency for highly volatile coals to ignite spontaneously.

Bituminous coal constitutes over 85 per cent. of the fuel used in manufacturing, when including the manufacture of coke. The term bituminous coal is broad in its interpretation, and includes a great variety of coals which have many different qualities. For this reason many of the coals of this classification are given special names depending upon some marked physical characteristic they possess. Dry or free burning bituminous coal is one of the best of the bituminous varieties for steaming purposes. As compared with other bituminous coals, it is low in volatile matter and burns with a short bluish flame. Bituminous caking coals is the term applied to those varieties that swell up, become pasty and fuse together in burning. They contain a greater amount of volatile matter than the dry bituminous coals and for that reason burn with a larger flame and have a greater tendency to smoke. Long flaming bituminous coals are those containing the greatest amounts of volatile matter. They possess a strong tendency to produce smoke. Cannel coal is a variety rich in volatile matter. It is used principally in the manufacture of artificial gas. It differs in appearance from the other varieties in that it has a dull resinous luster. Its volatile content varies from 45 to 60 per cent. It is seldom used as a steaming coal, though it is sometimes mixed with other coals containing less volatile matter.

Lignite may be classified as coal in the process of formation. This coal contains a very large proportion of volatile matter and less than 50 per cent. fixed carbon. However, it has a good heating value and burns freely, but owing to the high percentage of volatile matter it will not stand storage, but crumbles badly soon after exposure to air. Its use is restricted to those localities in which it is found.

Other solid fuels used to some extent for steam generation are: Peat, which is an intermediate between wood and coal and is found in bogs; sawdust; oak bark after it has been used in the process of tanning; bagasse, or the refuse of cane sugar; and cotton stalks. Coke is also used to some extent, the advantage of this fuel as compared with coal being that coke will not ignite spontaneously, will not deteriorate or decompose when exposed to the atmosphere, and produces no smoke when burned. Coke is manufactured by burning coal in a limited air supply, the volatile hydrocarbons being driven off during the process.

Petroleum fuels, either in the form of crude petroleum or as the refuse left from its distillation, are used for making steam to a considerable extent in certain parts where the relative cost of oil is less than that of coal. It has been estimated that petroleum oils at 2 c. per gallon are equally economical for steam making with coal at $3 per ton. The advantages of oil, as compared with solid fuels, are ease of handling, cleanliness, and absence of smoke after combustion. Table 3 gives the analysis and heating value of several American petroleum oils.

Table 3.—Analysis and Calorific Value of Oils (C. E. Lucke)

Classification	Density at 60°F.		Ultimate analysis				Heating value B.t.u. per lb.	
	gr.	°Bé.	C	H_2	O_2+N_2	S	High	Low
California fuel	0.966	14.93	81.52	11.61	6.92	0.55	18,926	17,903
Texas, Beaumont fuel	0.926	21.25	83.26	12.41	3.83	0.50	19,654	18,570
California crude	0.957	16.24	86.30	16.70	....	0.80	21,723	21,254
Texas, Beaumont crude	0.924	21.56	84.60	10.90	2.97	1.63	18,977	18,025
Pennsylvania crude	0.914	23.18	86.10	13.90	....	0.06	20,949	19,735
Kansas crude	0.866	31.67	85.40	13.07	....	....	20,345	19,203
West Virginia crude	0.841	36.47	84.30	14.10	1.6	....	20,809	19,578
Ohio crude	0.829	38.89	85.00	13.80	0.6	0.6	20,752	19,547

Natural gas is used for steam generation only in natural gas regions, where its cost is very low. If the cost of natural gas is greater than 10 cents per 1,000 cu. ft., it cannot compete with coal at $3 a ton. Illuminating gas and other artificial gas is too expensive for steam generation and cannot compete with other fuels. The heating values of various gaseous fuels will be found in Table 4.

TABLE 4.—HEATING VALUE OF GASEOUS FUELS

Character of Gas	B.t.u. per cu. ft.
Coke-oven Gas	600
Water Gas	275
Blast Furnace Gas	100
Natural Gas	950
Producer Gas	120

Fuels suitable for internal combustion engines are treated in Chapter XII.

Combustion.—Combustion is a chemical combination of the heat-producing constituents of a fuel with oxygen, accompanied by the evolution of heat.

Carbon, hydrogen, and sulphur are the main combustible constituents of all fuels. Of these, the sulphur is of minor importance in contributing to the heating value, because it is present in small quantities in fuels suitable for steam power plants. Carbon is present either in a free, uncombined state or in combination with hydrogen as a hydrocarbon.

Oxygen, the supporter of combustion, is one of the most common substances found in nature. The largest supply of oxygen is found in the atmosphere, and it is from this source that the supply required for the combustion of fuel is derived. Air is chiefly a mixture of oxygen and nitrogen, although small amounts of other gases are usually present.

Air contains 0.23 parts by weight of oxygen and 0.77 parts by weight of nitrogen. Only the oxygen is used in the combustion of the fuel; nitrogen is an inert gas and has no chemical effect upon the combustion of the fuel.

Chemistry of Combustion.—In the process of combustion, the heat producing elements of the fuel, which are carbon, hydrogen, and sulphur, unite with oxygen from the air.

If the combustion is perfect, the combustibles unite with the greatest amount of oxygen. Thus in the case of carbon, if the combustion is perfect, every atom of carbon unites with two atoms of oxygen forming carbon dioxide ($C + O_2 = CO_2$), and liberates 14,600 B.t.u. per pound.

If there is a lack of oxygen, combustion is imperfect, every atom of carbon unites only with one atom of oxygen forming carbon monoxide ($C + O = CO$) and liberating only 4,400 B.t.u. for each pound of carbon burned.

Hydrogen, when burned, enters into combination with oxygen, as indicated by the following chemical reaction, forming water (H_2O):

$$H_2 + O = H_2O$$

The sulphur unites with oxygen to form sulphur dioxide, as indicated by the following reaction:

$$S + O_2 = SO_2$$

The importance of proper air supply in the burning of a fuel is quite evident from the above. Each pound of carbon when completely burned is capable of liberating 14,600 B.t.u. If carbon is burned to carbon monoxide, only 4,400 B.t.u. will be liberated, producing a loss of 10,200 B.t.u., which is about 70 per cent. of the original heating value of the carbon. While it would be an extremely inefficient furnace that would produce much carbon monoxide, any furnace, unless properly operated, produces more or less incomplete combustion, with the consequent lower efficiency in the utilization of the fuel.

Air Required for Combustion.—For the complete combustion of one pound of carbon 2.66 pounds of oxygen, or 11.5 pounds of air will be theoretically required. Complete combustion will not be obtained in a boiler furnace if only this theoretical amount of air is supplied. An excess of air varying from 50 to 100 per cent. will be required, depending upon the draft and upon the fuel used. With natural draft, a greater excess of air is required than with mechanical draft.

Too much air will produce a great loss of heat by diluting the gases arising from the furnace. Air should be added to the furnace so that each atom of carbon has sufficient opportunity to unite with as much air as possible. When this is accomplished no further excess air is needed. Ordinarily, bituminous coal requires about 20 pounds of air per pound of fuel, or about 250 cubic feet of air per pound of fuel.

Flue Gas Analysis.—The analysis of the gases leaving the boiler is made to ascertain whether the fuel is being burned economically. If there is an excess of air, too much oxygen will be present in the flue gases; if there is a deficiency there will be carbon monoxide present.

Many instruments have been devised to facilitate this analysis. The fundamental principles upon which they operate are much the same. A simple device, called an *Orsat* apparatus and shown in Fig. 5, is commonly used. It consists of three pipettes, *A*, *B*, and *C*, filled respectively with caustic potash, a mixture of caustic potash and pyrogallic acid, and cuprous chloride. A measuring burette, *M*, and a displacement bottle, *W*, is also provided. The sample of the flue gas to be analyzed is drawn into the measuring burette. It is then passed into the pipette *A* containing the caustic potash where the carbon dioxide is

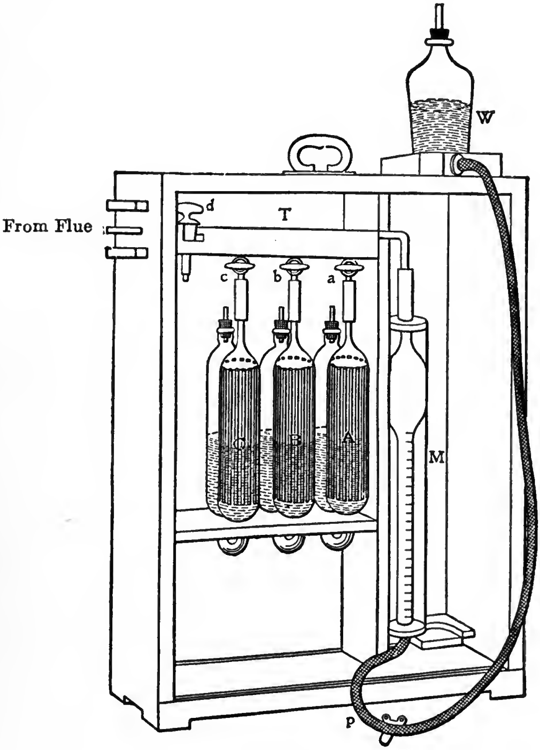


FIG. 5.—Orsat apparatus.

absorbed. The gas is then drawn back into the measuring burette and the shrinkage in volume represents the amount of carbon dioxide present. The remaining gas is similarly treated in pipette *B* where the oxygen is absorbed, and is finally passed to pipette *C* where the carbon monoxide is removed.

Perfect combustion is indicated by a flue gas analysis, which shows about 1 per cent. of carbon dioxide for every 4 per cent. of nitrogen. Low carbon dioxide may be due to excessive air, air holes in the fuel bed, or to the infiltration of air through cracks in the setting. Dirty heating surfaces and the presence of soot will be indicated by a low carbon dioxide in the flue gases. Too much oxygen in the flue gases shows excess of air. A good flue gas analysis will show 4 to 8 per cent. oxygen, 10 to 13 per cent. carbon dioxide, and no carbon monoxide.

Problems

1. Coal costs $3.00 a ton (2,000 lbs.). If the coal in question has a heating value of 12,000 B.t.u. per lb , what is the cost in cents of 1,000 B.t.u.?

2. Natural gas costs 15 c. per 1,000 cubic feet. If its heating value is 950 B.t.u. per cu. ft., what is the cost of 1,000 B.t.u.?

3. Fuel oil whose heating value is 18,500 B.t.u. per pound sells at 5 c. per gallon. Coal with a heating value of 13,000 B.t.u. per pound may be purchased at a price of $4.00 per ton. Which would be the cheaper fuel if the estimate is based upon the cost of an equal number of heat units?

4. Compile a table showing composition and heating value of the fuels most commonly used in your locality.

5. Prove that 2⅔ pounds of oxygen will be required to burn 1 pound of carbon into carbon dioxide.

6. Prove that 11½ pounds of air will be required to supply 2⅔ pounds of oxygen.

CHAPTER III

STEAM

Theory of Steam Generation.—If heat is added to ice, the effect will be to raise its temperature until the thermometer registers 32°F. When this point is reached a further addition of heat does not produce an increase in temperature until all the ice is changed into water, or in other words, the ice melts. It has been found experimentally that 144 B.t.u. are required to change 1 pound of ice into water. This quantity is called the latent heat of liquefaction of ice.

After the given quantity of ice, which for simplicity may be taken as 1 pound, has all been turned into water, it will be found that if more heat is added the temperature of the water will again increase, though not as rapidly as did that of the ice. While the addition of each British thermal unit increases the temperature of ice 2°F., in the case of water an increase of only about 1° will be noticed for each British thermal unit of heat added. This difference is due to the fact that the specific heat, or the resistance offered by ice to a change in temperature is only one-half that offered by water. That is, the specific heat of ice is 0.5.

If the water is heated in a vessel open to the atmosphere, its temperature will continue to rise until it reaches a temperature of about 212°F., the boiling point of water, when further addition of heat will not produce any temperature changes, but steam will issue from the vessel. It has been found that about 970 B.t.u. are required to change 1 pound of water at atmospheric pressure and at 212°F. into steam. The quantity of heat so supplied which changes the physical state of water from the liquid state to steam is called the latent heat of vaporization.

If the above operations are performed in a closed vessel, such as an ordinary steam boiler, water will boil at a higher temperature than 212°F., since the steam driven off cannot escape and is compressed, raising the pressure and consequently the temperature.

The fact that the boiling point of water depends on the pressure is well known. Thus in a locality where the altitude is 6,000 ft. above sea level and the barometric pressure is 12.6 pounds per square inch the boiling point of water is about 204°F. as compared with 212°F. at sea level where the barometric pressure is 14.7 pounds per square inch.

Assuming that the pressure is increased to 60 pounds per square inch by the gage, it will be found that the boiling point of water is 307.3°F. At 100 pounds per square inch water will boil at 337.9°F. and at 150 pounds the temperature will read 365.9°F. before steam will be formed.

Quality of Steam.—Steam formed in contact with water is known as saturated steam, which may be wet or dry.

In the first case steam carries with it a certain amount of water which has not been evaporated. The percentage of this water determines the condition or the quality of the steam; that is, if the steam contains 3 per cent. by weight of moisture, the steam is spoken of as being 97 per cent. dry. A stationary steam boiler, properly erected and operated and of suitable size, should generate steam that is 98 per cent. dry. If there is more than 3 per cent. moisture, there is every reason to believe that the boiler is improperly installed, inefficiently operated, has too small a space for the disengagement of the steam from the water, or is too small for the work to be done.

In the second condition, that of being dry steam, the vapor carries with it no water that has not been evaporated; that is, it is dry. Any loss of heat, however small, not accompanied by a corresponding reduction in pressure, will cause condensation, and wet steam will be the result. Steam, whether wet or dry, has a definite temperature corresponding to its pressure.

An increase in temperature not accompanied by an increase in pressure will cause the steam to acquire a condition that will permit a loss of heat at constant pressure without condensation necessarily following. This condition is called superheat. The advantage of superheated steam lies in the fact that its temperature may be reduced by the amount of superheat without causing condensation. This makes it possible to transmit the steam through mains and still have it dry and saturated at the time it reaches the engine cylinder. Superheated steam may be secured by passing saturated steam through coils of pipe in the path of the hot flue gases from the boiler to the chimney. An apparatus for superheating steam is called a superheater.

The pressure of steam will remain constant if it is used as fast as it is generated. If an engine uses steam too rapidly the boiler pressure will drop, and similarly if the fuel is burned at a constant rate and an insufficient amount of steam is used the pressure of the steam in the boiler will increase.

Steam Tables.—In Table 5 are given some of the most important properties of saturated steam, which include:

1. Pressure of steam in pounds per square inch absolute (p). This column gives the total pressure exerted and is the sum of the gage pressure which measures the pressures above that of the atmosphere and the atmospheric pressure as indicated by the barometer. A barometric reading of 30 inches corresponds to a pressure of 14.7 pounds per square inch.

Table 5.—Properties of Saturated Steam

(Marks and Davis)

ENGLISH UNITS

Abs. Pressure Pounds per Sq. in.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
.0886	32	0	1072.6	1072.6	3301.0	.000303	.0886
.2562	60	28.1	1057.4	1085.5	1207.5	.000828	.2562
.5056	80	48.1	1046.6	1094.7	635.4	.001573	.5056
1	101.8	69.8	1034.6	1104.4	333.00	.00300	1
2	126.1	94.1	1021.4	1115.5	173.30	.00577	2
3	141.5	109.5	1012.3	1121.8	118.50	.00845	3
4	153.0	120.9	1005.6	1126.5	90.50	.01106	4
5	162.3	130.2	1000.2	1130.4	73.33	.01364	5
6	170.1	138.0	995.7	1133.7	61.89	.01616	6
7	176.8	144.8	991.7	1136.5	53.58	.01867	7
8	182.9	150.8	988.1	1138.9	47.27	.02115	8

PROPERTIES OF SATURATED STEAM—*Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
9	188.3	156.3	984.8	1141.1	42.36	.02361	9
10	193.2	161.2	981.8	1143.0	38.38	.02606	10
11	197.7	165.8	979.0	1144.8	35.10	.02849	11
12	202.0	170.0	976.4	1146.4	32.38	.03089	12
13	205.9	173.9	974.0	1147.9	30.04	.03329	13
14	209.6	177.6	971.7	1149.3	28.02	.03568	14
14.7	212.0	180.1	970.4	1150.4	26.79	.03733	14.7
15	213.0	181.1	969.5	1150.6	26.27	.03806	15
16	216.3	184.5	967.4	1151.9	24.77	.04042	16
17	219.4	187.7	965.4	1153.1	23.38	.04277	17
18	222.4	190.6	963.5	1154.1	22.16	.04512	18
19	225.2	193.5	961.6	1155.1	21.07	.04746	19
20	228.0	196.2	959.8	1156.0	20.08	.04980	20
21	230.6	198.9	958.0	1156.9	19.18	.05213	21
22	233.1	201.4	956.4	1157.8	18.37	.05445	22
23	235.5	203.9	954.8	1158.7	17.62	.05676	23
24	237.8	206.2	953.2	1159.4	16.93	.05907	24
25	240.1	208.5	951.7	1160.2	16.30	.0614	25
26	242.2	210.7	950.3	1161.0	15.71	.0636	26
27	244.4	212.8	948.9	1161.7	15.18	.0659	27
28	246.4	214.9	947.5	1162.4	14.67	.0682	28
29	248.4	217.0	946.1	1163.1	14.19	.0705	29
30	250.3	218.9	944.8	1163.7	13.74	.0728	30
31	252.2	220.8	943.5	1164.3	13.32	.0751	31
32	254.1	222.7	942.2	1164.9	12.93	.0773	32
33	255.8	224.5	941.0	1165.5	12.57	.0795	33
34	257.6	226.3	939.8	1166.1	12.22	.0818	34
35	259.3	228.0	938.6	1166.6	11.89	.0841	35
36	261.0	229.7	937.4	1167.1	11.58	.0863	36
37	262.6	231.4	936.3	1167.7	11.29	.0886	37
38	264.2	233.0	935.2	1168.2	11.01	.0908	38
39	265.8	234.6	934.1	1168.7	10.74	.0931	39
40	267.3	236.2	933.0	1169.2	10.49	.0953	40
41	268.7	237.7	931.9	1169.6	10.25	.0976	41
42	270.2	239.2	930.9	1170.1	10.02	.0998	42
43	271.7	240.6	929.9	1170.5	9.80	.1020	43
44	273.1	242.1	928.9	1171.0	9.59	.1043	44
45	274.5	243.5	927.9	1171.4	9.39	.1065	45
46	275.8	244.9	926.9	1171.8	9.20	.1087	46

PROPERTIES OF SATURATED STEAM — *Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
47	277.2	246.2	926.0	1172.2	9.02	.1109	47
48	278.5	247.6	925.0	1172.6	8.84	.1131	48
49	279.8	248.9	924.1	1173.0	8.67	.1153	49
50	281.0	250.2	923.2	1173.4	8.51	.1175	50
51	282.3	251.5	922.3	1173.8	8.35	.1197	51
52	283.5	252.8	921.4	1174.2	8.20	.1219	52
53	284.7	254.0	920.5	1174.5	8.05	.1241	53
54	285.9	255.2	919.6	1174.8	7.91	.1263	54
55	287.1	256.4	918.7	1175.1	7.78	.1285	55
56	288.2	257.6	917.9	1175.5	7.65	.1307	56
57	289.4	258.8	917.1	1175.9	7.52	.1329	57
58	290.5	259.9	916.2	1176.1	7.40	.1351	58
59	291.6	261.1	915.4	1176.5	7.28	.1373	59
60	292.7	262.2	914.6	1176.8	7.17	.1394	60
61	293.8	263.3	913.8	1177.1	7.06	.1416	61
62	294.9	264.4	913.0	1177.4	6.95	.1438	62
63	295.9	265.5	912.2	1177.7	6.85	.1460	63
64	297.0	266.5	911.5	1178.0	6.75	.1482	64
65	298.0	267.6	910.7	1178.3	6.65	.1503	65
66	299.0	268.6	910.0	1178.6	6.56	.1525	66
67	300.0	269.7	909.2	1178.9	6.47	.1547	67
68	301.0	270.7	908.4	1179.1	6.38	.1569	68
69	302.0	271.7	907.7	1179.4	6.29	.1591	69
70	302.9	272.7	906.9	1179.6	6.20	.1612	70
71	303.9	273.7	906.2	1179.9	6.12	.1634	71
72	304.8	274.6	905.5	1180.1	6.04	.1656	72
73	305.8	275.6	904.8	1180.4	5.96	.1678	73
74	306.7	276.6	904.1	1180.7	5.89	.1699	74
75	307.6	277.5	903.4	1180.9	5.81	.1721	75
76	308.5	278.5	902.7	1181.2	5.74	.1743	76
77	309.4	279.4	902.1	1181.5	5.67	.1764	77
78	310.3	280.3	901.4	1181.7	5.60	.1786	78
79	311.2	281.2	900.7	1181.9	5.54	.1808	79
80	312.0	282.1	900.1	1182.2	5.47	.1829	80
81	312.9	283.0	899.4	1182.4	5.41	.1851	81
82	313.8	283.8	898.8	1182.6	5.34	.1873	82
83	314.6	284.7	898.1	1182.8	5.28	.1894	83
84	315.4	285.6	897.5	1183.1	5.22	.1915	84
85	316.3	286.4	896.9	1183.3	5.16	.1937	85

PROPERTIES OF SATURATED STEAM — *Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
86	317.1	287.3	896.2	1183.5	5.10	.1959	86
87	317.9	288.1	895.6	1183.7	5.05	.1980	87
88	318.7	288.9	895.0	1183.9	5.00	.2002	88
89	319.5	289.8	894.3	1184.1	4.94	.2024	89
90	320.3	290.6	893.7	1184.3	4.89	.2045	90
91	321.1	291.4	893.1	1184.5	4.84	.2066	91
92	321.8	292.2	892.5	1184.7	4.79	.2088	92
93	322.6	293.0	891.9	1184.9	4.74	.2110	93
94	323.4	293.8	891.3	1185.1	4.69	.2131	94
95	324.1	294.5	890.7	1185.2	4.65	.2152	95
96	324.9	295.3	890.1	1185.4	4.60	.2173	96
97	325.6	296.1	889.5	1185.6	4.56	.2194	97
98	326.4	296.8	889.0	1185.8	4.51	.2215	98
99	327.1	297.6	888.4	1186.0	4.47	.2237	99
100	327.8	298.4	887.8	1186.2	4.430	.2257	100
101	328.6	299.1	887.2	1186.3	4.389	.2278	101
102	329.3	299.8	886.7	1186.5	4.349	.2299	102
103	330.0	300.6	886.1	1186.7	4.309	.2321	103
104	330.7	301.3	885.6	1186.9	4.270	.2342	104
105	331.4	302.0	885.0	1187.0	4.231	.2364	105
106	332.0	302.7	884.5	1187.2	4.193	.2385	106
107	332.7	303.4	883.9	1187.3	4.156	.2407	107
108	333.4	304.1	883.4	1187.5	4.119	.2428	108
109	334.1	304.8	882.8	1187.6	4.082	.2450	109
110	334.8	305.5	882.3	1187.8	4.047	.2472	110
111	335.4	306.2	881.8	1188.0	4.012	.2493	111
112	336.1	306.9	881.2	1188.1	3.977	.2514	112
113	336.8	307.6	880.7	1188.3	3.944	.2535	113
114	337.4	308.3	880.2	1188.5	3.911	.2557	114
114.7	337.9	308.8	879.8	1188.6	3.888	.2572	114.7
115	338.1	309.0	879.7	1188.7	3.878	.2578	115
116	338.7	309.6	879.2	1188.8	3.846	.2600	116
117	339.4	310.3	878.7	1189.0	3.815	.2621	117
118	340.0	311.0	878.2	1189.2	3.784	.2642	118
119	340.6	311.7	877.6	1189.3	3.754	.2663	119
120	341.3	312.3	877.1	1189.4	3.725	.2684	120
121	341.9	313.0	876.6	1189.6	3.696	.2706	121
122	342.5	313.6	876.1	1189.7	3.667	.2727	122
123	343.2	314.3	875.6	1189.9	3.638	.2749	123

Properties of Saturated Steam — *Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
124	343.8	314.9	875.1	1190.0	3.610	.2770	124
125	344.4	315.5	874.6	1190.1	3.582	.2792	125
126	345.0	316.2	874.1	1190.3	3.555	.2813	126
127	345.6	316.8	873.7	1190.5	3.529	.2834	127
128	346.2	317.4	873.2	1190.6	3.503	.2855	128
129	346.8	318.0	872.7	1190.7	3.477	.2876	129
130	347.4	318.6	872.2	1190.8	3.452	.2897	130
131	348.0	319.3	871.7	1191.0	3.427	.2918	131
132	348.5	319.9	871.2	1191.1	3.402	.2939	132
133	349.1	320.5	870.8	1191.3	3.378	.2960	133
134	349.7	321.0	870.4	1191.4	3.354	.2981	134
135	350.3	321.6	869.9	1191.5	3.331	.3002	135
136	350.8	322.2	869.4	1191.6	3.308	.3023	136
137	351.4	322.8	868.9	1191.7	3.285	.3044	137
138	352.0	323.4	868.4	1191.8	3.263	.3065	138
139	352.5	324.0	868.0	1192.0	3.241	.3086	139
140	353.1	324.5	867.6	1192.1	3.219	.3107	140
141	353.6	325.1	867.1	1192.2	3.198	.3128	141
142	354.2	325.7	866.6	1192.3	3.176	.3149	142
143	354.7	326.3	866.2	1192.5	3.155	.3170	143
144	355.3	326.8	865.8	1192.6	3.134	.3191	144
145	355.8	327.4	865.3	1192.7	3.113	.3212	145
146	356.3	327.9	864.9	1192.8	3.093	.3233	146
147	356.9	328.5	864.4	1192.9	3.073	.3254	147
148	357.4	329.0	864.0	1193.0	3.053	.3275	148
149	357.9	329.6	863.5	1193.1	3.033	.3297	149
150	358.5	330.1	863.1	1193.2	3.013	.3319	150
152	359.5	331.2	862.3	1193.5	2.975	.3361	152
154	360.5	332.3	861.4	1193.7	2.939	.3403	154
156	361.6	333.4	860.5	1193.9	2.903	.3445	156
158	362.6	334.4	859.7	1194.1	2.868	.3487	158
160	363.6	335.5	858.8	1194.3	2.834	.3529	160
162	364.6	336.6	858.0	1194.6	2.801	.3570	162
164	365.6	337.6	857.2	1194.8	2.768	.3613	164
166	366.5	338.6	856.4	1195.0	2.736	.3655	166
168	367.5	339.6	855.5	1195.1	2.705	.3697	168
170	368.5	340.6	854.7	1195.3	2.674	.3739	170
172	369.4	341.6	853.9	1195.5	2.644	.3782	172
174	370.4	342.5	853.1	1195.6	2.615	.3824	174
176	371.3	343.5	852.3	1195.8	2.587	.3865	176

PROPERTIES OF SATURATED STEAM — *Concluded*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
178	372.2	344.5	851.5	1196.0	2.560	.3907	178
180	373.1	345.4	850.8	1196.2	2.532	.3949	180
182	374.0	346.4	850.0	1196.4	2.506	.3990	182
184	374.9	347.4	849.3	1196.7	2.480	.4032	184
186	375.8	348.3	848.5	1196.8	2.455	.4074	186
188	376.7	349.2	847.7	1196.9	2.430	.4115	188
190	377.6	350.1	847.0	1197.1	2.406	.4157	190
192	378.5	351.0	846.2	1197.2	2.381	.4200	192
194	379.3	351.9	845.5	1197.4	2.358	.4242	194
196	380.2	352.8	844.8	1197.6	2.335	.4284	196
198	381.0	353.7	844.0	1197.7	2.312	.4326	198
200	381.9	354.6	843.3	1197.9	2.289	.4370	200
202	382.7	355.5	842.6	1198.1	2.268	.4411	202
204	383.5	356.4	841.9	1198.3	2.246	.4452	204
206	384.4	357.2	841.2	1198.4	2.226	.4493	206
208	385.2	358.1	840.5	1198.6	2.206	.4534	208
210	386.0	358.9	839.8	1198.7	2.186	.4575	210
212	386.8	359.8	839.1	1198.9	2.166	.4618	212
214	387.6	360.6	838.4	1199.0	2.147	.4660	214
216	388.4	361.4	837.7	1199.1	2.127	.4700	216
218	389.1	362.3	837.0	1199.3	2.108	.4744	218
220	389.9	363.1	836.4	1199.5	2.090	.4787	220
222	390.7	363.9	835.7	1199.6	2.072	.4829	222
224	391.5	364.7	835.0	1199.7	2.054	.4870	224
226	392.2	365.5	834.3	1199.8	2.037	.4910	226
228	393.0	366.3	833.7	1200.0	2.020	.4950	228
230	393.8	367.1	833.0	1200.1	2.003	.4992	230
232	394.5	367.9	832.3	1200.2	1.987	.503	232
234	395.2	368.6	831.7	1200.3	1.970	.507	234
236	396.0	369.4	831.0	1200.4	1.954	.511	236
238	396.7	370.2	830.4	1200.6	1.938	.516	238
240	397.4	371.0	829.8	1200.8	1.923	.520	240
242	398.2	371.7	829.2	1200.9	1.907	.524	242
244	398.9	372.5	828.5	1201.0	1.892	.528	244
246	399.6	373.3	827.8	1201.1	1.877	.532	246
248	400.3	374.0	827.2	1201.2	1.862	.537	248
250	401.1	374.7	826.6	1201.3	1.848	.541	250
275	409.6	383.7	819.0	1202.7	1.684	.594	275
300	417.5	392.0	811.8	1203.8	1.547	.647	300
350	431.9	407.4	798.5	1205.9	1.330	.750	350

2. Temperatures of saturated steam in degrees Fahrenheit (*t*). This column of temperatures shows the vaporization temperature, or the boiling point, at each of the given pressures.

3. Heat of the liquid (*h*), or the heat required to bring up the temperature of a pound of water from freezing point to boiling point at the given pressure.

4. The latent heat (*L*), or the heat required to vaporize a pound of water into dry steam at the given pressure, after the boiling point is reached.

5. The total heat of the steam (*H*), which is the sum of the heat of the liquid and the latent heat, and represents the total heat that is required to generate dry saturated steam from water at the freezing point, at the various pressures.

6. The volume of 1 pound of dry steam (*v*) at the various pressures.

7. Density of dry steam in pounds per cubic foot $\left(\frac{1}{v}\right)$.

To illustrate the use of the steam tables the following examples will be solved:

Example 1.—Water at 200°F. is fed to a boiler in which the pressure is 100 pounds per square inch gage. How much heat must be supplied by the fuel to evaporate each pound of water into dry steam?

Solution.—A pressure of 100 pounds per square inch gage $= 100 + 14.7 = 114.7$ pounds per square inch absolute, if the barometer reading is 30 in.

The heat required to evaporate one pound of water from freezing point into dry steam at a pressure of 114.7 lb. per square inch absolute is the total heat of steam (*H*) at the pressure, or 1188.6.

Since the water fed to the boiler has a temperature of 200°F., the total amount of heat to be supplied by the fuel to evaporate one pound of water into dry steam is:

$$1188.6 - (200 - 32) = 1020.6 \text{ B.t.u.}$$

Example 2.—If the steam in example 1, contained 3 per cent. moisture, calculate the heat which must be supplied by the fuel to evaporate each pound from feed water at 200°F.

Solution.—The heat of the liquid, or the heat required to raise the temperature of a pound of water from 200°F. to the boiling point corresponding to a pressure of 114.7 pounds per square inch absolute is:

$$308.8 - (200 - 32) = 140.8 \text{ B.t.u.}$$

The heat required to vaporize a pound of water into dry steam at 114.7 pounds per square inch absolute, after the boiling point is reached, is 879.8 B.t.u.

Since the steam in this example contains 3 per cent moisture, it is 97 per cent. dry, and the heat required to vaporize it is:

$$879.8 \times 0.97 = 853.4 \text{ B.t.u.}$$

The total heat required to change one pound of water at 200°F. into steam, 3 per cent. wet, and at a pressure of 114.7 pounds per square inch absolute is:

$$140.8 + 853.4 = 994.2 \text{ B.t.u.}$$

Example 3.—What is the volume of one pound of steam at 150 lbs. per square inch absolute, if it is 20 per cent. wet?

Solution.—Dry steam at a pressure of 150 lbs. per sq. in. absolute has a volume of 3.013 cu. ft. per pound.

The volume of one pound of steam which is 20 per cent. wet, or 80 per cent. dry, at a pressure of 150 pounds per square inch absolute is:

$$3.013 \times 0.80 = 2.41 \text{ cubic feet.}$$

Determination of the Quality of Steam.—The quality, or the per cent. of moisture in saturated steam, is determined by means of a calorimeter. There are three types of steam calorimeters in general use,—the Throttling Calorimeter, the Separating Calorimeter, and the Electrical Calorimeter.

The throttling calorimeter is the most accurate instrument for measuring the amount of moisture in steam. This instrument depends for its action upon the fact that steam, nearly dry, becomes superheated when its pressure is reduced by throttling, since saturated steam at high pressure contains more heat than at low pressure. A simple type of throttling calorimeter is illustrated in Fig. 6. O is the orifice discharging into the chamber C, into which a thermometer T is inserted. A mercury manometer is attached at V_3.

Let P_1 equal the absolute pressure of the steam in the main steam pipe. The heat contained in one pound of steam at the pressure P_1 would be the sum of the heat of the liquid (h_1) and the latent heat of steam (L_1) corrected for the moisture, or

$$h_1 + xL_1$$

where x is the quality of the steam.

If the steam has a pressure P_2, as indicated by the manometer, attached to V_3, after it passes the orifice O, and a temperature t_s, as registered by the thermometer T, the heat contained in one pound of steam at the pressure P_2 would be the total heat (H_2) of dry saturated steam at the lower pressure plus the heat due to the superheat. The heat due to the superheat is calculated by multiplying the degrees of superheat by the specific heat of superheated steam at the given pressure and temperature. By specific heat is meant the resistance which a substance offers to a change in its temperature. The average value of the specific heat of superheated steam (C_P) at the temperatures and pressures common in calorimeters is 0.47. The degrees of superheat are determined by subtracting the saturated temperature (t_2) corresponding to the lower pressure, as measured by the manometer at V_3, from the temperature t_s, as indicated by the thermometer T of the steam calorimeter.

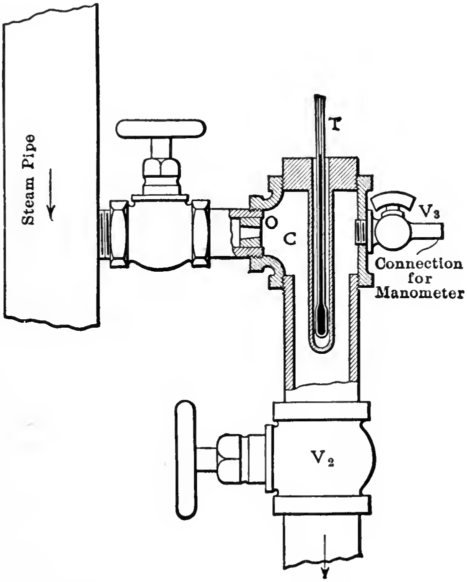


FIG. 6.—Throttling steam calorimeter.

Since the total heat in the steam is the same on both sides of the calorimeter:

$$h_1 + xL_1 = H_2 + 0.47(t_s - t_2)$$

Solving for x, the quality of steam is calculated as follows:

$$x = \frac{H_2 + 0.47\ (t_s - t_2) - h_1}{L_1}$$

Example.—Steam is tested by means of a throttling calorimeter. Find the per cent. of moisture in the steam if the gage pressure of the steam in the main steam pipe is 115.3, the pressure in the calorimeter, as indicated by the manometer at V_3 (Fig. 6), two inches of mercury, and the temperature of the calorimeter thermometer at T (Fig. 6) 260°F.

Solution.—$P_1 = 115.3 + 14.7 = 130$ pounds per square inch absolute.

$h_1 = 318.6$

$L_1 = 872.2$

$P_2 = 14.7 + (2 \times 0.491) = 15.68$. (One inch of mercury is equal to 0.491 pounds pressure per square inch.)

$H_2 = 1151.4$

$t_2 = 215.3$

$$x = \frac{1151.4 + 0.47\,(260 - 215.3) - 318.6}{872.2} = 0.978$$

Per cent. of moisture $= 100 - 97.8 = 2.2$

The throttling calorimeter is unsuitable for measuring the quality of steam which contains more than 3 or 4 per cent. moisture.

The amount of moisture in very wet steam can best be determined by a separating calorimeter, illustrated in Fig. 7. Steam enters the separating calorimeter at A (Fig. 7), passes down the vertical pipe, plugged at the lower end, from which it escapes through a large number of holes as indicated. The moisture collects at the bottom of the vessel V and can be measured by the calibrated glass gage G. The steam leaves the calorimeter at N and can be collected, condensed and weighed. The gage P indicates the pressure in the jacket J. This pressure is roughly proportional to the flow of steam through the nozzle N. The gage P is usually provided with a scale to indicate the approximate flow of steam. The per cent. of moisture is calculated by dividing the weight of water collected in the gage glass G by the sum of the weights of steam passing out at N and of the water at G.

The electrical calorimeter consists of an electric heater which is used for drying and for superheating the steam. The amount of electric energy required to dry the steam is proportional to the amount of moisture in the steam.

Problems

1. A boiler generates steam at a pressure of 120 pounds by the gage. If the barometric pressure is 28.5 in., calculate the absolute pressure in pounds per square inch.

2. Calculate the heat required to change 20 pounds of water at a temperature of 190°F. into dry steam at 150 pounds per square inch absolute.

3. If the steam in problem 2 contains 5 per cent. moisture, calculate the heat required.

4. Compare the volumes of one pound of steam at the following pressures in pounds per square inch absolute: ½, 1, 2, 14.7, 100, 150, 200, 300.

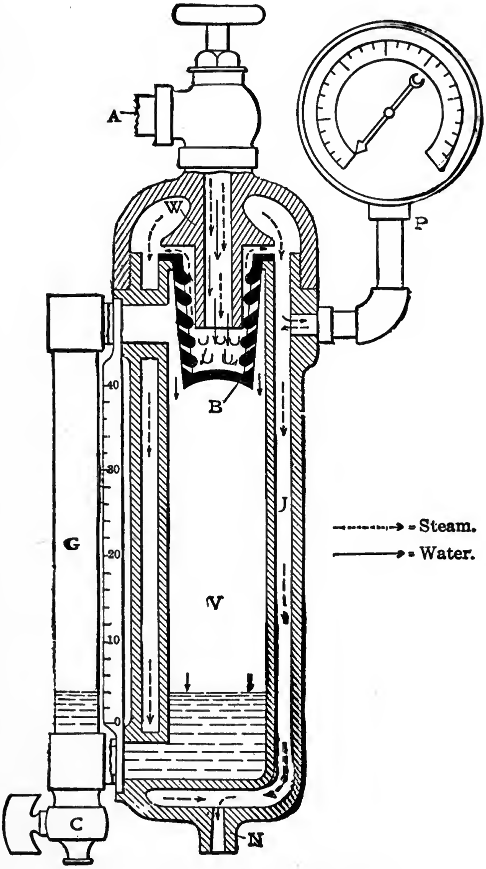


Fig. 7.—Separating calorimeter.

5. A plain cylindrical boiler has a diameter of 30 inches and a length of 12 feet. If two-thirds of the volume of the boiler is filled with water at a temperature of 270°F., the other third with steam, calculate:

(*a*) Boiler pressure in pounds per square inch gage if the barometer is 29.2 inches.

(*b*) Calculate the weight of the water and the weight of the steam contained in the boiler.

6. The quality of steam at a pressure of 140 pounds per square inch gage is measured by means of a throttling calorimeter. If the calorimeter thermometer reads 270°F. and the manometer registers 3 inches of mercury, calculate the quality of the steam.

7. Prove that the throttling calorimeter will be unsuitable for measuring the quality of steam which has 10 per cent. moisture at a steam pressure of 150 pounds per square inch gage.

8. Steam is tested by means of a separating calorimeter (Fig. 7) and gives the following results:

Water collected in the glass gage *G*.	0.25 lb.
Steam collected at *N*.	0.90 lb.

Calculate the quality of the steam.

CHAPTER IV

BOILERS

The function of a boiler is to generate steam to be used either in engine cylinders, or for heating purposes. The term boiler is commonly applied to the combination of the furnace in which the fuel is burned and the boiler proper, which is a closed vessel containing water and steam.

Classification of Boilers.—Boilers are divided into two classes, the fire-tube and the water-tube. In the fire-tube boiler (Fig. 9) the hot gases developed by the combustion of the fuel pass through the tubes, while in the water-tube boiler (Fig. 18) these gases pass around the tubes. Either type may be constructed as a vertical or as a horizontal boiler, depending on whether the axis of the shell is vertical or horizontal.

The fire-tube boiler may be externally or internally fired. In the externally fired boiler (Fig. 10) the furnace is in the brick setting entirely outside of the boiler shell, while in the internally fired types (Figs. 13 and 14) the furnace is in the boiler shell, no brick setting being necessary. For stationary work the externally fired boiler is the most common, while the internally fired types are always used for locomotive and traction engine purposes, and generally for marine power plants. Vertical fire-tube boilers are usually internally fired.

Plain Cylindrical Boiler.—The plain cylindrical type of boiler is practically obsolete, but it is of interest because of its simplicity. Fig. 8 illustrates a longitudinal cross-section of such a boiler. It consists of a cylindrical shell closed at its two ends by dished heads. Because of the circular shaped heads, no staying is necessary. The chief disadvantage in the use of this type of boiler is the small amount of heating surface it contains, which means that an extremely large boiler is necessary for small evaporative effects.

Horizontal Return Tubular Boiler.—Boilers of this type are most commonly used in this country. They are simple, inexpensive, have a large overload capacity, and are economical when properly handled. The general appearance of a return tubular boiler is shown in Fig. 9. Fig. 10 illustrates the details of the setting.

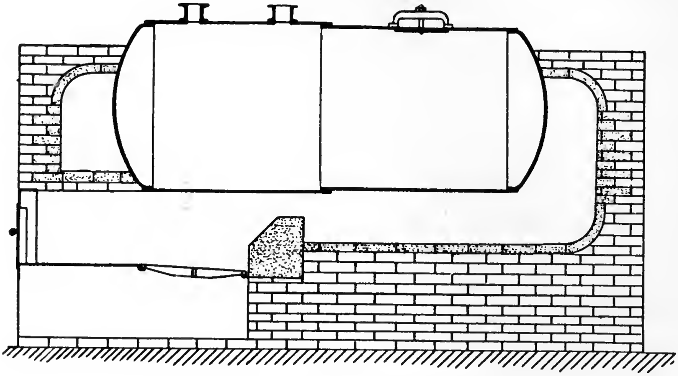


Fig. 8.—Plain cylindrical boiler.

These boilers consist of a cylindrical shell closed at the ends by two flat heads, and of numerous small fire tubes which extend the whole length of the shell. The fire tubes are three or four inches in diameter and 14 to 18 feet long. About two-thirds of the volume of the shell is filled with water, the other third,

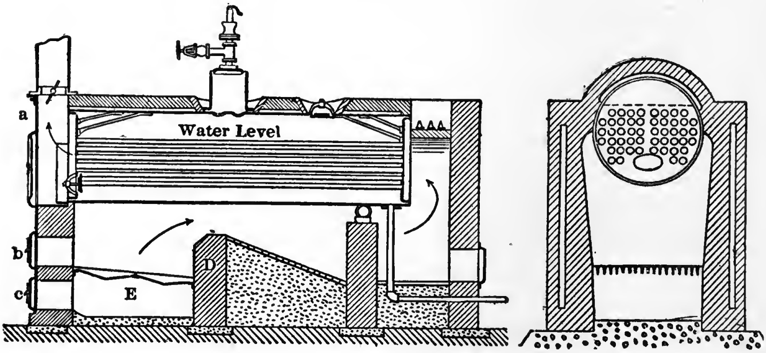


Fig. 9.—Return tubular boiler.

called the steam space, being left for the disengagement of the steam from the water. The water line is about six inches above the top row of fire tubes. Sometimes, as shown in Fig. 11, a steam dome *D* is provided to increase the volume of the steam space. Steam domes are seldom used in modern boilers for stationary power plants, as they weaken the boiler shell and add to the first cost of the boiler.

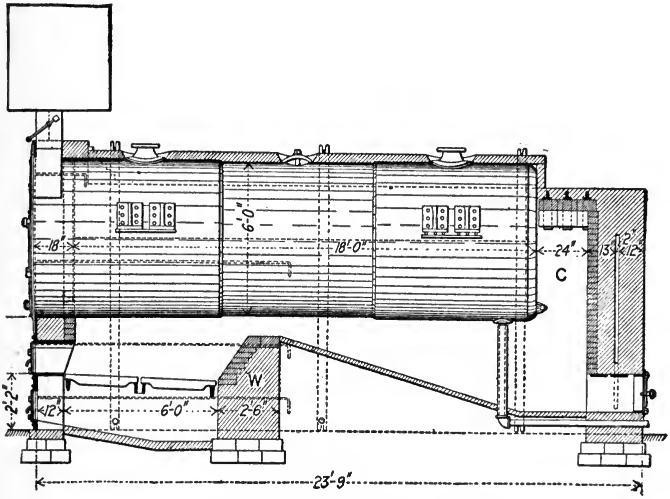


Fig. 10.—Details of boiler setting.

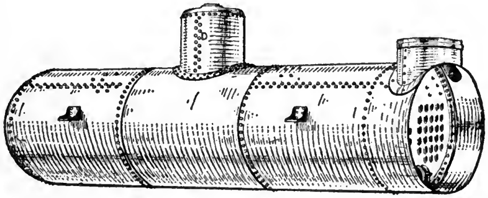


Fig. 11.—Boiler with dome.

The coal is burned upon the grates which, as shown in Fig. 10, rest upon the bridge wall *W* and upon the front of the setting. The hot gases, formed by the combustion of the fuel, pass from the furnace under and along the boiler shell to the back connection, or combustion chamber *C*, from there to the front through the tubes, and up the uptake to the breeching or flue, which leads to the chimney.

The distance between the grates and the boiler shell should be greater for bituminous than for anthracite coal. This distance, in the case of the best anthracite coal, may be as little as 24 inches, but for bituminous coal the distance between the grates and the boiler should be more than 36 inches. The greater this distance the more opportunity will be given for the proper combustion of the fuel.

This type of boiler is usually provided with a hand-hole or a man-hole in front below the tubes, and with a man-hole in the top of the boiler.

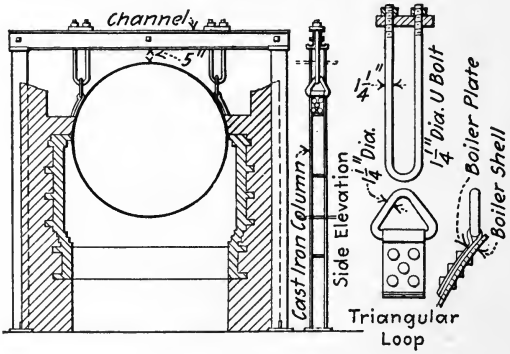


Fig. 12.—Independent method of setting boiler.

The flat heads, or tube sheets of the boiler, are stayed below the water line by the tubes. Above the water line special stays must be provided to prevent the tube sheets from distorting. In Fig. 9 the distortion of the tube sheet above the tubes is prevented by the use of diagonal stays which transfer the strain to the shell of the boiler.

Boilers of this type are usually set in brick settings. In some cases the boiler is supported by brackets, as shown in Fig. 10. In this case the front brackets rest on metal plates embedded in the brickwork of the side walls, while the back brackets are placed on rollers, which in turn rest on horizontal plates, this method allowing the back of the boiler to move as the shell expands or contracts. A better method is to support the boiler independent of the setting, on steel framework, as shown in Fig. 12.

The setting should be constructed so that the hot gases will not come in contact with the shell above the water line.

Scotch Marine Boiler.—A single ended, two furnace Scotch marine boiler is shown in Fig. 13. This boiler differs from those previously described in that it is internally fired. The boiler consists of a cylindrical shell enclosed at its two ends by flat plates. The furnace flues are connected to a combustion chamber. Numerous fire tubes fill the upper portion of the boiler. The travel of gases is first through the furnace-flues, then to the combustion chamber, and finally through the tubes to the uptake and stack.

Boilers of this type are self contained, require little overhead room, and no setting. The rear surface of the combustion chamber is stayed by connecting it to the rear head by means of short bolts, termed stay bolts. The front surface of the combustion chamber is stayed by the furnace flues and the tubes, while the top of the chamber is supported by a bar which transmits the strain to the two side sheets and is termed a girder stay. The heads of the boiler above the tubes are supported by through stays, which are rods connecting both heads as shown. Large boilers of this type are provided with furnaces at both ends which open into a common combustion chamber in the middle of the boiler.

Locomotive Boiler.—Fig. 14 illustrates a locomotive boiler. A type similar to the one shown is used in stationary work. The stationary type, however, is only made in comparatively small sizes and finds its application only in isolated locations, or where steam is required temporarily. The type used in locomotive practice as well as that used in stationary work is classified as a fire-tube, internally fired boiler.

The locomotive boiler consists of a cylindrical shaped barrel or shell which contains a large number of fire-tubes. The furnace or fire-box is constructed by extending the shell downward to form the sides. The walls of the fire-box are made double, the space thus created being connected to the water space in the shell. This extension of the plates to form the sides of the fire-box produces two narrow sections which are filled with water,

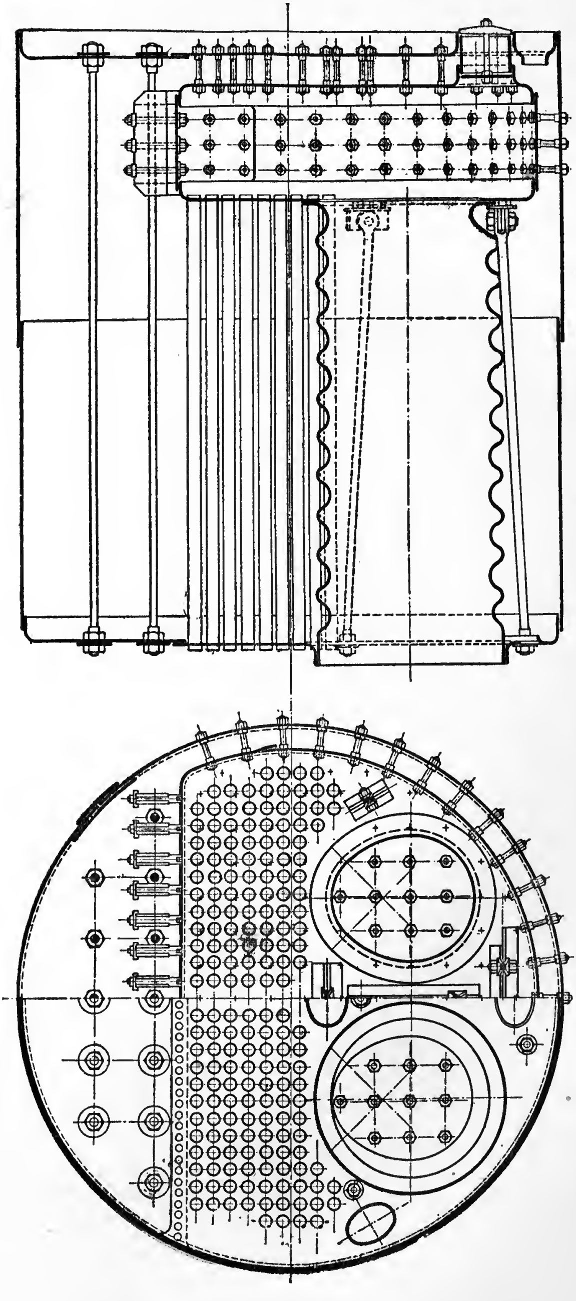


FIG. 13.—Scotch marine boiler.

forming what is usually termed a water leg. These boilers are constructed with a steam dome from which the steam is taken.

The hot gases leave the furnace, pass through the small tubes to the smoke box at the front of the boiler, and from there to the stack.

The flat sheets composing the water legs are stayed by the use of small stay bolts. The same method of staying is applied to the sheet forming the top of the fire box, but in this case the name "crown stays" is usually applied.

Vertical Fire-tube Boilers.—Two forms of vertical boilers are shown in Figs. 15 and 16. In the form shown in Fig. 15 the tops of the tubes are above the water line, and may become overheated when the boiler is forced. To prevent injury from this cause, some forms of vertical boilers are constructed as shown in Fig. 16, the tops of the tubes being ended in a submerged tube sheet, which is kept below the water line.

The essential parts of all forms of vertical boilers are a cylindrical shell with a fire-box and ash pit in

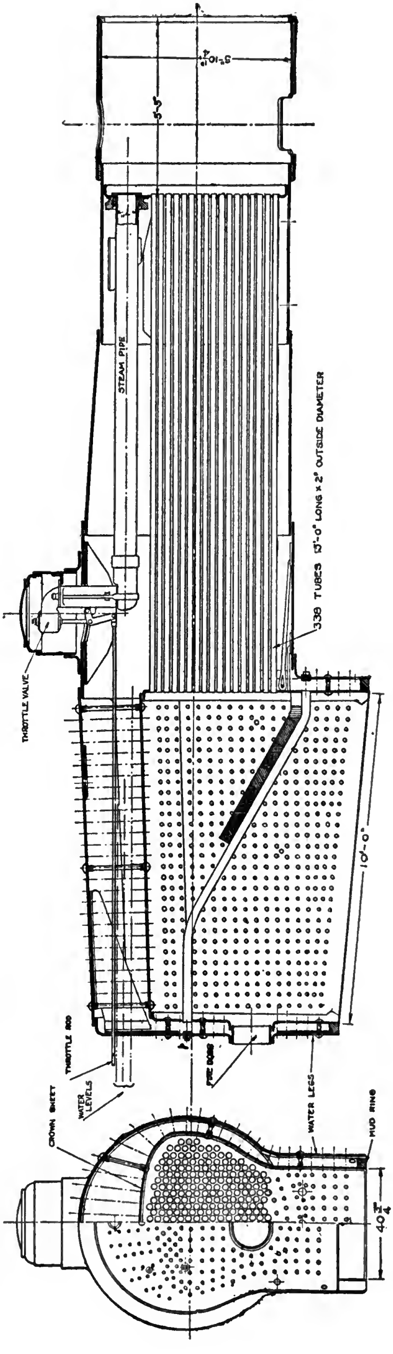


FIG. 14.—Locomotive boiler.

the lower end. The tubes lead directly from the furnace to the upper head of the shell. The hot gases from the furnace pass through the tubes and out of the stack.

Vertical boilers occupy little floor space, require no setting except a light foundation, and are inexpensive. To offset these advantages, vertical boilers, as ordinarily constructed, are uneconomical, have small capacity, have too little space for the disengagement of the steam, and are inaccessible for thorough inspection and cleaning.

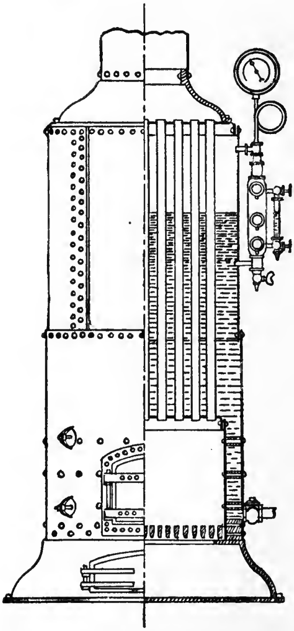


Fig. 15.—Vertical boiler exposed tube type.

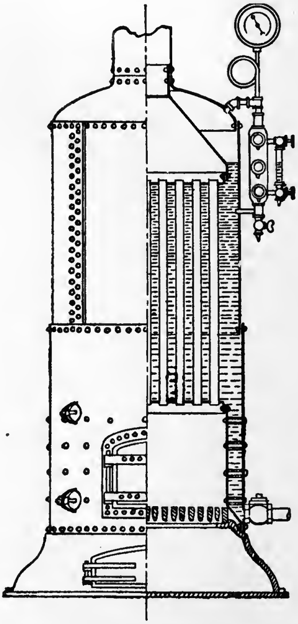


Fig. 16.— Vertical boiler submerged tube type.

Fig. 17 illustrates one of the larger vertical boilers, known as the Manning type. The tubes in this boiler are much longer than those usually installed in vertical boilers of the types previously discussed, consequently the heating surface is greatly increased. The shell is enlarged at the fire-box to provide for a larger furnace and more grate area. No staying is required in this boiler except at the water leg, and at this point the inner sheet of the fire-box is joined to the outer shell by stay bolts.

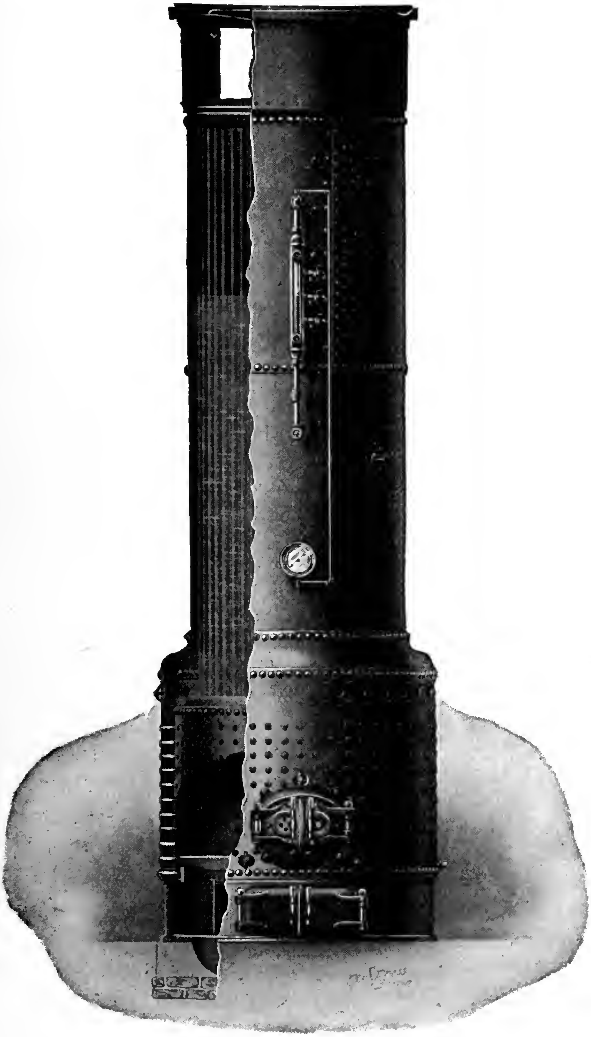


Fig. 17.—Manning vertical boiler.

Water Tube Boilers.—Water tube boilers are used in large power plants on account of their adaptability to higher steam pressures and larger sizes, decreased danger from serious explosions, greater space economy, and rapidity of steam generation. For small power plants and for steam pressures of 125 pounds or less the fire tube boiler is usually more suitable on account of its lower first cost. Also in a fire-tube boiler, if a tube should break, the boiler can be repaired by plugging without seriously interrupting service, which is not the case with most types of water tube boilers. As far as efficiency is concerned, numerous tests show that either type, when properly designed and operated, will give the same economy.

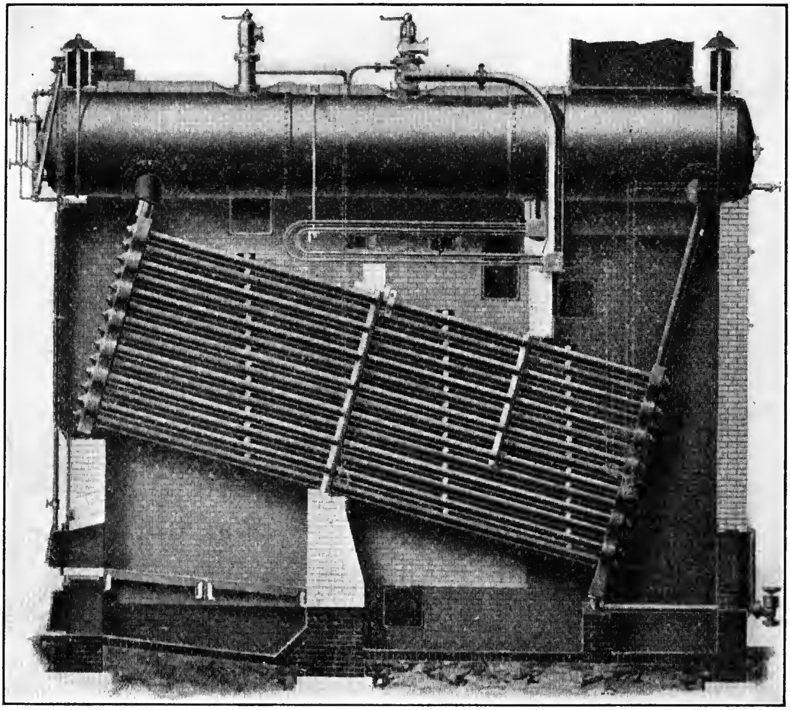


Fig. 18.—Babcock and Wilcox Boiler.

There are many different types of water tube boilers, but the essential parts of all are much the same. They consist of numerous tubes filled with water, and one or more drums for the disengagement of the steam from the water. No tubes run through the drums, consequently dished heads may be used, thus eliminating the necessity for staying.

The Babcock & Wilcox Boiler.—Fig. 18 shows the Babcock and Wilcox type of water tube boiler. This boiler consists of a number of straight tubes fastened into several sets of headers which are connected to a common drum. The feed water enters the boiler through a pipe passing through the front end of the drum and extending back about one-third of its length. Opposite the end of each tube there is provided a hand hole through which the tubes may be inspected or cleaned. The hot gases from the furnace are deflected by means of fire brick baffle plates and the bridge wall and pass across the tubes three times before reaching the uptake at the rear of the boiler. In some cases the baffling is arranged so that the gases are directed along the tubes. The boiler is supported by steel beams resting on columns independent of the setting.

The Heine Boiler.—The Heine boiler is illustrated in Fig. 19. It consists of a number of straight tubes, expanded into two water legs or headers of flanged steel plate, which are connected to a common drum. The tubes are parallel to the drum. Opposite the end of each tube is a hand hole to facilitate cleaning and inspection. The feed water enters the boiler through the front head, passes into a mud drum, where the impurities are deposited, circulates from the front toward the back in the drum, and from the back toward the front in the tubes. The baffle plates in this type of boiler are usually arranged horizontally so that the hot gases pass first to the rear of the boiler, then back through the nest of tubes to the front, and finally back to the stack, coming in contact with the drum of the boiler in this last pass. This boiler is supported independently of the setting at the front end, while the rear water leg rests upon the rear wall.

Stirling Boiler.—Fig. 20 shows a sectional elevation of a Stirling water tube boiler. This boiler consists of four horizontal cylindrical drums, three at the top and one large drum at the bottom. A series of inclined water tubes connect the upper drums with the lower. Tubes are used to connect the steam spaces of the upper drums so that any steam formed in these may be transmitted to the middle drum. Similarly a series of tubes connects the front and middle drums below the water line. Such a connection limits the main circulation within the boilers to the front and middle bank of tubes.

The feed water enters the rear upper drum, flows downward through the rear bank of tubes to the bottom drum, where the impurities are deposited, and then upward through the front bank of tubes. The rear system of tubes acts as a feed water heater.

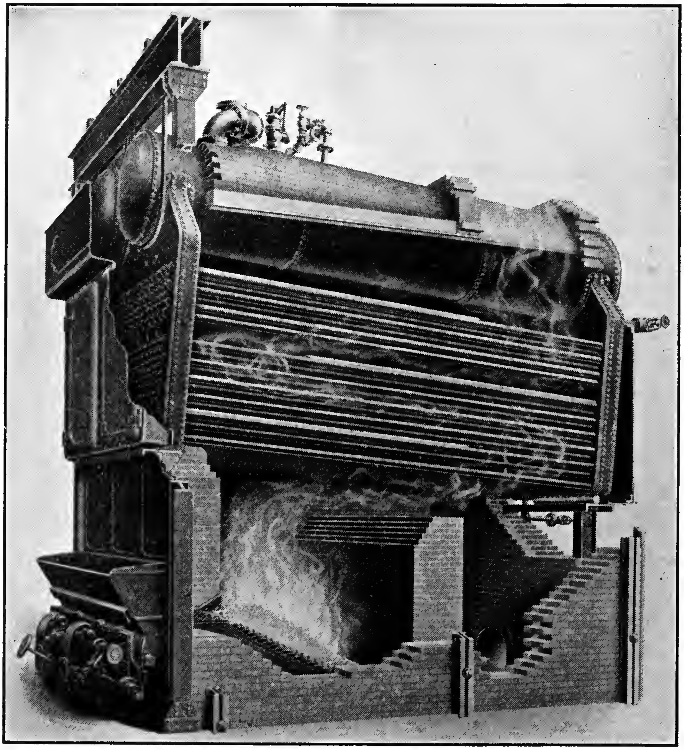


Fig. 19.—Heine boiler.

The steam formed during the passage upward through the front tubes becomes separated from the water in the front drum and passes into the middle drum, which is connected with the steam main. The safety valve is located on the top of the middle drum.

The baffle walls are set so that the hot gases from the furnace pass over the bridge wall, and thence upward through the first bank of tubes. It then passes downward through the second set of tubes, and finally upward through the remaining set to the stack. Thus the water and hot gases circulate in opposite directions.

Wickes Boiler.—Fig. 21 illustrates the Wickes vertical water tube boiler. This boiler consists primarily of two cylinders joined together by straight tubes. The tubes are divided into two sets by a baffle wall which passes through their center. The whole boiler is erected in a vertical position and is surrounded by brickwork.

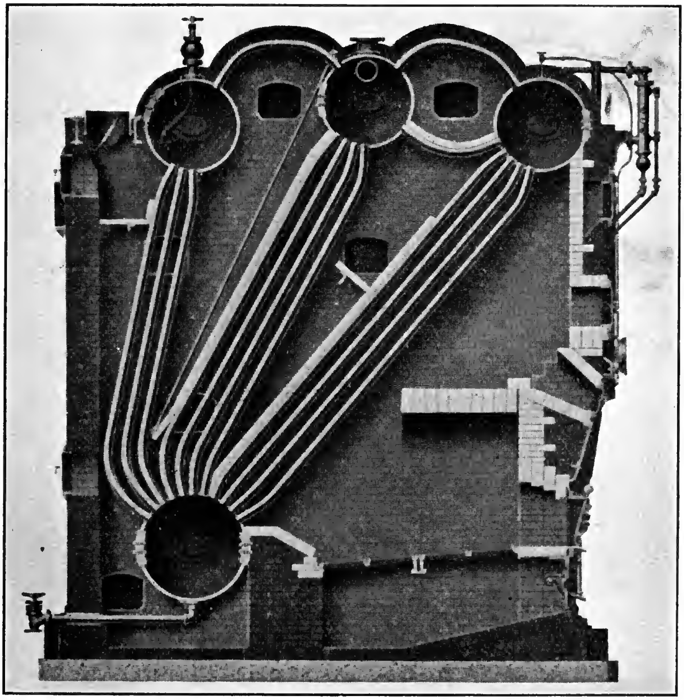


Fig. 20.—Stirling water tube boiler.

The gases generated in the furnace pass upward through the forward compartment, and are directed downward through the rear compartment. The hotter gases thus come in contact with the front tubes, while the cooler gases surround those at the rear.

This causes the main circulation within the boiler to be upward through the front and downward through the rear compartment.

Parker Down Flow Boiler.—The Parker boiler is illustrated in Fig. 22, and consists of a cylindrical drum inside of which is a diaphragm separating the steam space from the water space.

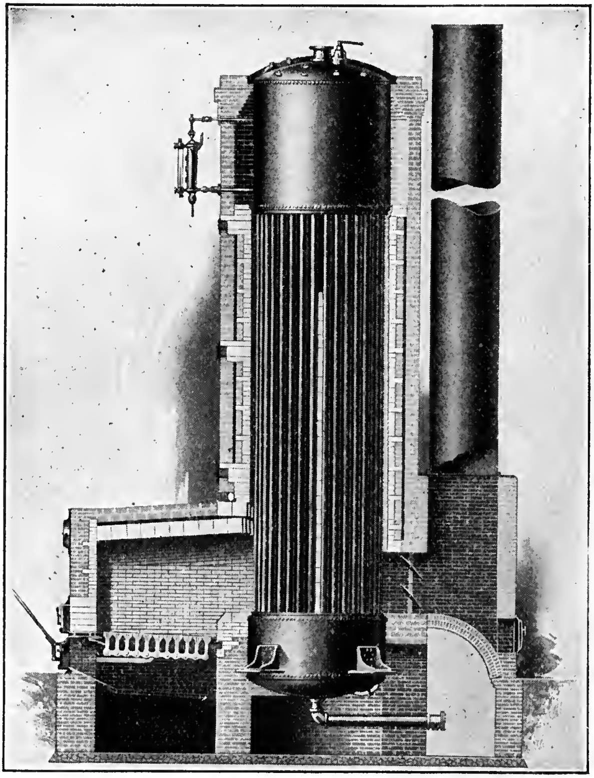


FIG. 21.—Wickes vertical boiler.

The tubes are arranged to form a series of continuous passages, termed elements, leading downward from the water chamber, and are finally directed upward from the bottom ends to the steam chamber. A check valve at the top of each element prevents the reversal of flow. The straight tubes form the continuous elements by expanding them into junction boxes, which are provided with a hand-hole opening opposite each tube.

The water fed into the drum seeks its level in the elements. When heat is applied the water in the elements is soon discharged as steam into the drum. The water then runs down from the drum in an effort to retain its level which is made impossible by the continuous evaporation. As a result, there is a rapid flow of water and steam downward through the tube elements impelled by the gravity head of water.

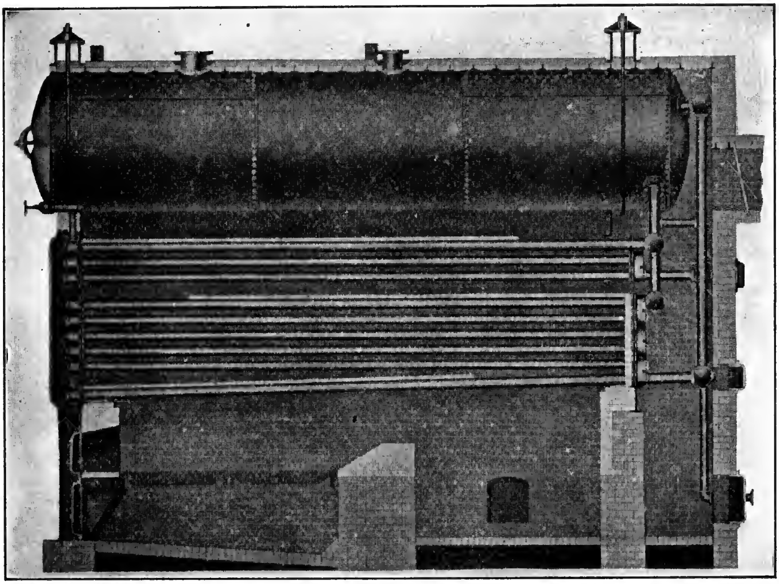


FIG. 22.—Parker down-flow boiler.

The locations of the tube elements and of the baffle walls are arranged in such a manner that the gases and water circulate in opposite directions. This principle brings the hottest steam in contact with highly heated gases, and steam at the lower temperature in contact with cooler gases.

This boiler as in the case of most of the others of the water-tube type is supported independently of the boiler setting.

Marine Water Tube Boilers.—The service to which a boiler is to be applied modifies its design. Several types of water tube boilers have been designed and have been found well adapted to marine work. The main requirements for a successful boiler in this class of service are that it should occupy little space and have a large evaporative capacity.

Fig. 23 illustrates a water-tube boiler of the Babcock and Wilcox type, designed for marine service. It consists of a cylindrical drum whose axis is at right angles to those of the tubes, or is crossed. The tubes are connected to headers, but the size of these tubes is smaller and the number of them larger than is common in the stationary type.

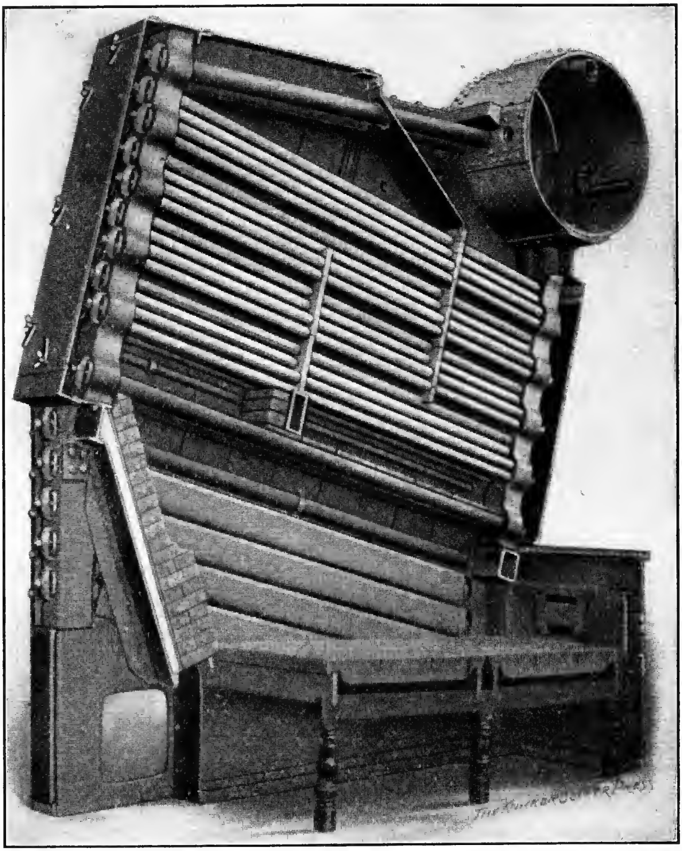


FIG. 23.—Babcock and Wilcox Marine boiler.

Materials.—Boilers intended for power purposes are made of rolled steel plates riveted together. Steel is the most desirable material for the construction of a boiler because of its strength and cheapness, and also because of its ductility, which permits the material to be formed into the irregular shapes necessary in constructing the boiler. Boiler tubes are made of steel and are usually lap welded.

Cast iron is not generally considered a suitable material. It is brittle, possesses practically no ductility, and often produces unsound castings. It is used only in the construction of house heating boilers, as in this class of service high pressures are not necessary.

Copper is used in boiler construction in special cases, as in fire engine boilers, where the use of a material of less strength and greater cost is permissible in order to obtain a quick steaming boiler.

Heating Surface.—The heating surface of a boiler is that surface which is exposed to the flame and hot gases. This term is expressed in square feet, and the general rule employed in its calculation is to measure that part of the surface which is in contact with the flame or gases. For example, the heating surfaces of a boiler tube would be calculated by multiplying the internal circumference of the tube in feet by its length in feet if the tube was surrounded by water upon its external surface, and its internal surface was in contact with hot gases, as is the case in fire-tube boilers. If this condition is reversed, as is the case in water-tube boilers, the heating surface would be calculated by multiplying the external circumference of the tube by its length.

In a horizontal return tubular boiler, the heating surface is calculated by taking two-thirds of the cylindrical surface of the shell, adding to this the internal area of all the tubes, plus two-thirds of the area of both tube sheets and subtracting from the result twice the combined external cross-sectional area of all the tubes.

The heating surface of a boiler is proportional to its capacity, or to the ability of a boiler to evaporate water into steam. The larger the quantity of water to be evaporated by a boiler, the larger must be its heating surface.

Staying.—Cylindrical or spherical surfaces retain their shape when subjected to either a bursting or to a collapsing pressure.

Surfaces having a flat shape tend to become circular or spherical when a pressure is exerted. This tendency of flat boiler plates to distort when pressure is applied is prevented by the use of stays, as was pointed out in connection with the various types of boilers. There are many different types of stays; but in general they consist of small rods which connect the surfaces to be stayed and transfer the strain either to the shell of the boiler or to some other surface. These stays are given special names, depending upon their general construction, their mode of connection, or the type of surface to which they are best suited.

Settings and Furnaces.—In building a boiler setting the solid brick wall is preferable to the hollow wall. If the wall is built in two parts, the space should be filled with ash, crushed brick or sand, as loose material reduces air leakage by its plasticity.

Proper furnace design will aid in the economical combustion of coal. The design of a furnace should be modified to suit local fuels. To burn coals rich in volatile matter, the furnace must be so designed that the gases given off from the fuel bed remain at a high temperature until the combustion process is complete. This means that the combustion chamber for a high volatile coal must be large enough for the air to mix with the gases given off from the fuel bed and before such gases come into contact with the cool heating surfaces of the boiler. This can be accomplished by the use of an extension furnace, such as the Dutch oven type, or by having the heating surfaces elevated at a considerable distance above the grate. The more volatile matter the coal contains, the greater should be the distance between the grate and the shell or the tubes of the boiler. The baffling for water tube boilers should be arranged so that the hot gases from the fuel bed come first into contact with the baffles at the bottom of the tubes.

Air infiltration through cracks in boiler setting reduces the economy of a boiler plant. Visible cracks in the setting should be covered. The practice of encasing the whole setting in sheet steel, or the application of asbestos cement on the outside of the setting, should be employed more generally. Radiation losses can be reduced by the use of insulating brick.

Sufficient ash pit capacity should be available to handle the refuse from at least a 12-hour run. In calculating the size of an ash pit, the weight of ashes can be assumed at 40 to 50 pounds per cubic foot. In plants where the ashes have to be handled by hand, it is important that the ash pit be so arranged as to be readily cleaned.

Capacity and Efficiency of Steam Boilers.—Boilers are usually rated in horsepower. The term horsepower in this connection is only a matter of convenience, and does not mean the rate of doing work; boiler horsepower is an arbitrary unit which is applied to the evaporation of a definite amount of water. The amount of power developed by a steam power plant per unit weight of steam generated by the boiler depends upon the engine used. The American Society of Mechanical Engineers has recommended that one boiler horsepower should mean the evaporation of 30 pounds of water per hour at 100°F. into steam at 70 pounds gage. This is equivalent to the evaporation of $34\frac{1}{2}$ pounds of water per hour from feed water at 212°F. into dry steam at the same temperature.

Another method of expressing boiler horsepower is in terms of heat. To evaporate one pound of water from a temperature of 212°F. into steam at 212°F. only the latent heat of evaporation at that temperature is required. From the steam tables page 24, we find that the latent heat of steam at 212°F. is 970.4 B.t.u. The amount of heat required to evaporate 34.5 pounds from and at 212°F. would be:

$$34.5 \times 970.4 = 33{,}479 \text{ B.t.u.}$$

Thus a boiler horsepower may be stated as the absorption by the water within the boiler of 33,479 B.t.u. per hour.

As was previously mentioned, the capacity of a boiler depends upon its heating surface. Boiler manufacturers often rate boilers in square feet of heating surface. One square foot of boiler heating surface can evaporate economically 3 to 3.4 pounds of water, so that a boiler horsepower can be produced by 10 to 12 square feet of boiler heating surface. For fir -tube boilers it is customary to assume 10 to 12 square feet of heating surface as representing one boiler horsepower; in water-tube boilers 10 square feet of heating surface is equivalent to one boiler horsepower.

The following example will illustrate the application of these terms:

Example.—A boiler evaporates 4,000 pounds of water per hour into dry steam The steam pressure is 100 pounds per square inch absolute, and the feed water enters the boiler at a temperature of 132°F What boiler horsepower is generated?

Solution.—The heat required to evaporate one pound of the water under these conditions will be found by reference to the steam tables page 26 to be

$$1{,}186.2 - (132 - 32) = 1{,}086.2 \text{ B.t.u.}$$

The total heat absorbed by the water per hour is

$$4{,}000 \times 1{,}086.2 = 4{,}344.800 \text{ B.t.u.}$$

Since 33,479 B.t.u. is the rate of absorption of heat per boiler horsepower, the power generated by the boiler is

$$\frac{4{,}344{,}800}{33{,}479} = 129.8 \text{ boiler horsepower.}$$

Under good working conditions, a boiler will evaporate 8 to 12 pounds of water per pound of coal, and 11 to 18 pounds of water per pound of petroleum fuel. The economy of a boiler plant depends upon the quality of the fuel used, the design of the furnace and boiler, the condition of setting, and the care in firing.

The efficiency of a boiler is the ratio of the heat units absorbed by the steam per pound of fuel fired, to the heat units supplied by one pound of the fuel. Tests show that the efficiencies of boilers will vary under ordinary working conditions from about 40 per cent. for small vertical boilers to about 85 per cent. when well designed boilers are carefully handled. A boiler under average conditions should show an efficiency of about 70 per cent. The main losses in a boiler are the heat carried away by the flue gases, the loss of fuel through grates, the loss due to poor combustion of the fuel, and the heat lost by radiation.

The amount of heat required to produce one pound of steam depends upon the temperature of the feed water, the steam pressure, and the quality of the steam. In order to compare boilers working under different conditions, the economy of boilers is expressed as the equivalent evaporation from and at 212°F. This means that the actual evaporation per pound of fuel is reduced to the number of pounds of water which would be evaporated if the feed water had been supplied to the boiler at 212°F., and that dry steam was formed at that temperature which is the boiling point of water at atmospheric pressure.

Example.—A boiler generates 9 pounds of steam per pound of fuel from feed water at 203°F. Calculate the equivalent evaporation from and at 212°F., if the steam pressure is 160 pounds per square inch absolute and the quality steam 0.98 dry.

Solution.—The heat required to evaporate 9 pounds of feed water at 203°F. into steam which has a pressure of 160 pounds absolute and a quality 0.98 is equal to:

$$9[335.5 - (203 - 32) + 0.98(858.8)] = 9054.9 \text{ B.t.u.}$$

In order to evaporate water at 212°F. into steam at the same temperature, 970.4 B.t.u. will be required, therefore the equivalent evaporation in accordance with the conditions of the above problem will be:

$$\frac{9054.9}{970.4} = 9.33 \text{ lb.}$$

Firing.—To the average person, firing consists merely of opening the furnace door and throwing fuel on the grate. This is, however, a fallacy. It has been found that some system of firing must be adopted in order to produce economical combustion of coal. The method to be adopted depends mainly on the kind of fuel used.

The spreading method consists of distributing a small charge of coal in a thin layer over the entire grate. This system of firing will give satisfactory results with anthracite coal and with some bituminous coals. With this method, if the fuel is fed in large quantities and at long intervals, incomplete combustion will result.

The alternate method consists of covering first one side of the grate with fresh fuel and then the other. The volatile gases that pass off from the fresh fuel on one side of the grate are burned with the hot air coming from the bright side of the fire. This system is best applied to a boiler with a broad furnace.

The coking method is best adapted for the smoky and for the caking varieties of bituminous coal. In this method the coal is put in the front part of the furnace, and allowed to remain there until the volatile gases are driven off; it is then pushed back and spread over the hot part of the furnace, and a new charge is thrown in the front.

Either one of the three systems of firing explained will produce good results, if properly carried out and if the fire is kept bright and clean. Smoke indicates incomplete combustion and with bituminous coal occurs if the volatile gases are allowed to pass off unburned.

Management of Boilers.—Before a boiler is started for the first time, its interior should be carefully cleaned, care being taken that no oily waste or foreign material is left inside the boiler. The various manholes and handholes are then closed and the boiler is filled to about two-thirds of its volume with water. The fire is started with wood, oily waste, or some other rapidly burning materials, keeping the damper and ashpit door open. The fuel bed is then built up slowly.

While getting up the steam pressure, the water gage glass should be blown out to see that it is not choked, the gage cocks should be tried, and all auxiliaries such as pumps, injectors, pressure gages, piping, etc., carefully inspected. The safety valve should be carefully examined and tried out before cutting the boiler into service.

When cutting a boiler into service with others, its pressure should be the same as that of the other boilers. Steam valves should be opened and closed very slowly in order to prevent water-hammer and stresses from rapid temperature changes.

During the operation of a steam boiler the safety valve should be kept in perfect condition and tried daily by allowing the pressure to rise gradually until the valve begins to simmer. Each boiler should have its own safety valve and under no conditon should a stop valve be placed between it and the boiler. The steam gage should be calibrated from time to time with a standard gage, or still better by means of some form of dead-weight tester. It is best not to depend on the water gage glass entirely. Gage cocks are more reliable and should be used for checking the water level of a boiler.

In case of low water, do not turn on the feed, but shut the damper, cover the fuel bed with ashes, or if that is not available, with green coal. The safety valve should not be lifted until the boiler has cooled down, as an explosion may occur. Also do not change operating conditions as regards the use of steam. If the engine is running allow it to continue but do not open valves to reduce the pressure.

A boiler should be cleaned often and kept free from scale.

If water free from impurities is used a boiler may be run several months without fear of serious scale formation, but in most places boilers should be cleaned at least once a month. When preparing to clean a boiler, allow it to cool down, and the water to remain in the shell until you are ready to commence cleaning.

In emergencies split tubes of fire-tube boilers may be plugged without throwing the boiler out of service. Also if a tube becomes leaky in the tube-sheet the fault can be remedied by inserting a tapering sleeve slightly larger than the inside diameter of the tube.

A boiler should aways be thoroughly inspected before it is started. In the case of the locomotive type of boiler the crown sheet should be given particular attention.

Problems

1. Calculate the heating surface of a fire-tube boiler to which you have access, after taking the necessary measurements.

2. Calculate the boiler horsepower of the boiler in Problem 1.

3. A boiler plant operating under a pressure of 135 pound per sq. in. gage generates 18,000 pounds of saturated steam per hour. If the feed water temperature is 203°F. and the quality of the steam 3 per cent. wet, calculate the boiler horsepower of the plant.

4. Calculate the approximate heating surface of the boiler plant in Problem 3, assuming fire-tube boilers.

5. Prove that 34½ pounds of water per hour from and at 212°F. is the same as the evaporation of 30 pounds of water per hour from feed water at 100°F. into steam at 70 pounds gage pressure.

6. Compare the equivalent evaporation from and at 212°F. of the following boilers:

Boiler *A* evaporates 7½ pounds of water per hour from feed water at 140°-F. and into steam at a pressure of 140 pounds gage, with 2 per cent. priming.

Boiler *B* evaporates 8½ pounds of water per hour from feed water at 205°F. and into steam at a pressure of 150 pounds gage, with 4 per cent. priming.

7. Why is a solid wall preferable to a hollow wall for a boiler setting?

8. Why will air infiltration through cracks in a boiler setting interfere with the economy of a boiler plant?

9. What causes a boiler to explode?

10. Examine some power plant to which you have access and hand in report showing the following: type of boilers used, steam pressure carried, methods used for setting boilers (use sketches), and temperature of feed water; also the relation between the rating of the boilers in horsepower and the maximum capacity of the power plant in horsepower or kilowatt.

CHAPTER V

BOILER AUXILIARIES

SUPERHEATERS

Types of Superheaters.—The boilers considered in the last chapter have been designed for the generation of saturated steam. Boilers which are intended for superheated service must be supplied with superheaters. The installation of a superheater increases the amount of heat available in the boiler plant and makes greater economies possible in the utilization of the steam in steam engines and in steam turbines. Superheated steam reduces the losses of heat in piping systems, as superheated steam gives up heat less readily than saturated steam.

The cost of a superheater depends upon the type and size, as well as upon the degree of superheat maintained. Ordinarily the installation of a superheater will add about one-third to the cost of a steam boiler, but the capacity of the boiler plant will be greatly increased.

Two types of superheaters are used, the independently fired and the attached type. The independently fired superheater, as its name indicates, is placed in an independent setting and is fired by a separate furnace. The attached superheaters are located directly in the boiler setting, or in the flue leading from the boiler, derive their heat from the same furnace as the boiler, and are consequently subject to the fluctuating temperatures of the furnace. In the independently fired superheater the degree of superheat is independent of the boiler furnace. By means of the independently fired superheaters higher temperatures are possible than with the attached superheaters. The independently fired superheater is, however, more expensive in first cost, costs more to operate, and occupies considerable space, as compared with the attached superheater.

Practically all superheaters consist of a series of tubes expanded into rectangular steel headers through which the steam from the boiler passes before entering the piping leading to the engine. Heat from the furnace gases is thus absorbed by the flowing steam and its temperature is raised above that at which it left the boiler.

To prevent a superheater from overheating some provision must be made to protect it during the firing up of the boiler, or at such other times when the flow of steam through the superheater is small. This provision has given rise to several designs. Superheaters which consist of plain steel tubes in contact with the flue gases at all times, can be protected by flooding. This is accomplished by allowing water to pass through the superheater until the steam flow is at such a rate as to prevent overheating. Other superheaters are protected by deflecting the furnace gases by means of dampers, the flow of gases over the superheating surface being

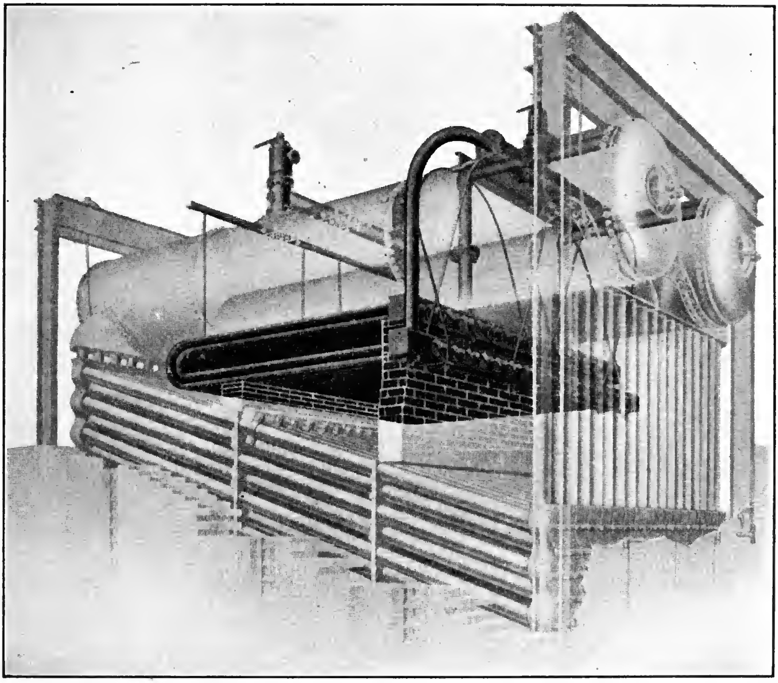


Fig. 24.—Babcock and Wilcox superheater.

controlled by the operator. In other types, the tubes are protected by cast iron fins or rings which surround each tube. Cast iron is capable of withstanding higher temperatures than steel; by its use the steel tubes are protected and no flooding or other protective device is necessary.

Babcock & Wilcox Superheater.—Fig. 24 illustrates a Babcock & Wilcox Superheater attached to a boiler of the same type.

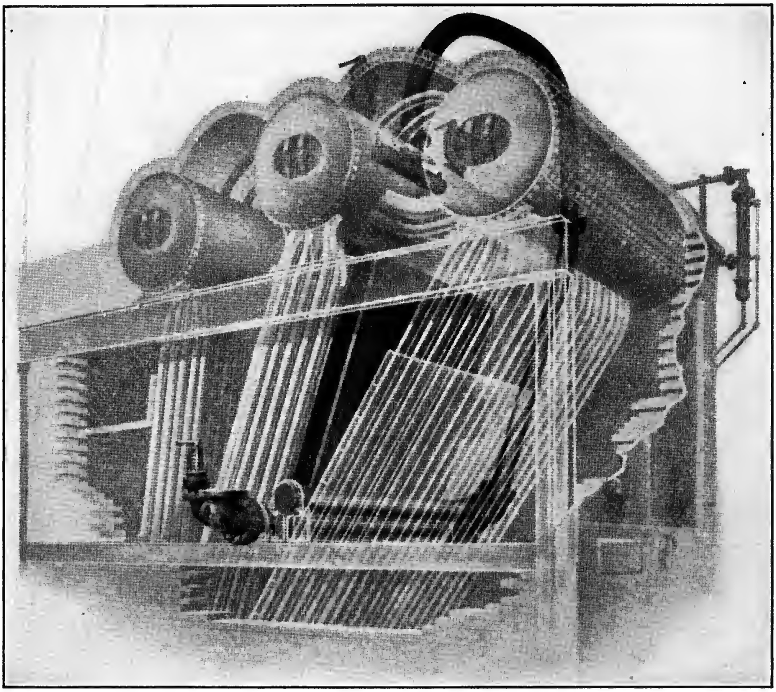


Fig. 25.—Stirling boiler with attached superheater.

The superheater is located directly under the boiler drums between the first and second pass of the boiler. It consists of a series of steel tubes expanded into steel headers. The saturated steam from the boiler drum enters the top header and passes through the tubes to the bottom header. The superheated steam is conducted from the bottom header to the main piping.

Stirling Superheater.—Fig. 25 illustrates a Stirling superheater attached to a Stirling boiler. The arrangement of this boiler and superheater, differs from the Stirling boiler for saturated steam, by the installation of the superheater in place of the middle bank of tubes. The superheater consists of two drums connected by a series of steel tubes. By the use of diaphragms and valves located in the two drums the steam makes a circuitous path through the superheating elements. This superheater is made of steel tubes which are in the path of the furnace gases, and are protected from overheating by flooding. The pipe connection for flooding is indicated in the illustration shown.

Heine Superheater.—The Heine superheater, shown in Fig. 26, differs from the types just discussed in that it is not placed directly in the path of the flue gases, but is located in such a manner that the flow of the flue gases over the superheating surface may be controlled. This is accomplished by installing the superheater at the top of the setting near the side of the steam drum. The superheater is enclosed in a brick setting which is provided with two openings. One opening is near the rear of the superheater and is connected to the furnace gas chamber by a small brick flue, which extends downward from the superheater and

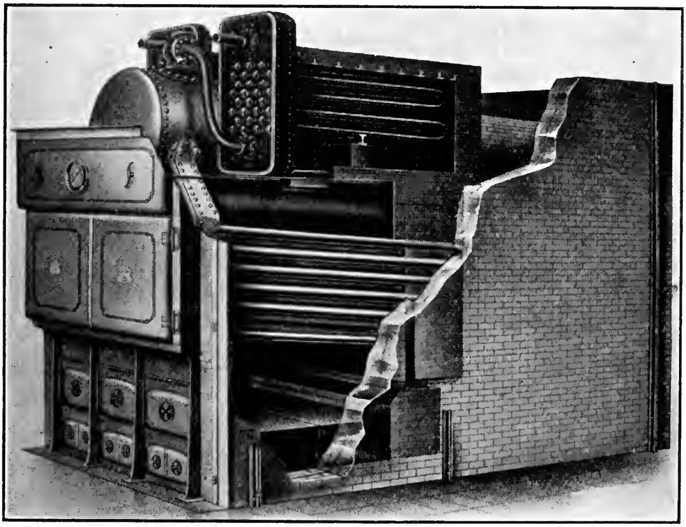


Fig. 26.—Heine superheater.

terminates near the bridge wall. The other opening, which is provided with a damper, is near the front of the superheater and connects with the flue gases as they pass from the boiler. The amount of superheat can be regulated by varying the quantity of gases passing over the superheating surface. The superheater consists of a number of U-shaped tubes connected to a steel header. The header is divided into three compartments.

Foster Superheater.—The Foster superheater makes use of the special tube as illustrated in Fig. 27. The superheater tubes are double and the outer tubes are protected by cast iron rings. By the use of an inner and outer tube, the steam flows against the heated surface in a thin stream, thus increasing the effectiveness of the superheating surface. The cast iron rings protect the outer tube from overheating, so that no flooding is necessary.

The Foster tubes are used in connection with the separately fired types as well as with the attached types of superheaters.

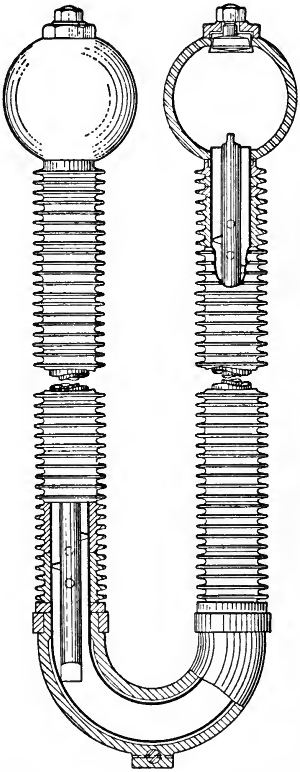


Fig. 27.—Foster superheater element.

MECHANICAL STOKERS

The Field of Mechanical Stokers.—Greatest fuel economy can be secured by firing coal frequently and in small quantities. With hand firing this is difficult to accomplish and usually more coal is put into the furnace at one time than is desirable for economical combustion. Mechanical stokers make possible the feeding of small quantities of fuel at regular intervals, the time between the charges being so regulated that the fuel is completely burned. When using mechanical stokers the rate of firing is even, smoke can be greatly reduced, the furnace doors can be kept closed, and the air supply regulated to suit the fuel and the load. Low grade fuels which cannot be burned without smoke by hand-firing methods, are frequently used successfully with certain types of mechanical stokers.

Mechanical stokers are an absolute necessity in large power plants on account of the saving in labor. In very small plants, stokers are not often used on account of the initial high cost and the expenses in connection with the operation and upkeep of the stoker mechanism. Stokers are practical in plants as small as 500-boiler horsepower, if inferior grades of fuel must be used, the skill of the firemen is low, or smoke must be kept down to a minimum.

The cost of upkeep is higher for stokers than for hand-fired furnaces, and is influenced by the size and by the composition of the fuel used. For best results lumps three inches or smaller should be used. The initial cost of stoker equipment depends upon the size and number of stokers installed, the draft available, and the kind of fuel.

Mechanical stokers are usually classified into three general types: the chain-grate, the inclined grate, and the underfeed type. The type of stoker to be selected depends upon the kind of fuel to be burned.

Chain-grate Stokers.—Fig. 28 illustrates a typical chain-grate stoker. The entire grate surface is made of a large number of chain-links, which form the fuel bearing surface. Sagging of the upper grate surface is prevented by supporting the weight of the upper grate on small rollers.

Power for driving the stoker is applied at the front. This causes the top side of the grate to revolve slowly from the front of the furnace toward the rear. Coal is fed upon the moving grate through the hopper in the front and is burned as it passes toward the bridge-wall. Under proper operating conditions, the speed of the traveling grate is adjusted so that the coal will have been completely burned to ash when it reaches the end of the grate and will drop down into the ash pit below. The speed of the chain grate must be regulated in accordance with the load on the boiler and the grade of coal used. Care must be taken in regulating the speed of the grate to prevent loss of fuel to the ashpit. Leakage of air between the grate and the bridge wall and through the fire bed at the rear must be reduced to a minimum by regulating the depth of the fuel and ash beds.

This type of stoker is usually operated with natural draft. The entire grate is mounted upon wheels so that it can be removed from the furnace for the purpose of making repairs. A coking arch of fire brick extends over the top of the grate and acts as an incandescent surface upon which the volatile gases strike as they are distilled from the coal. This promotes the complete combustion of the gases, which, if allowed to strike the cooler boiler surface, would be cooled below their ignition temperature and smoke would result.

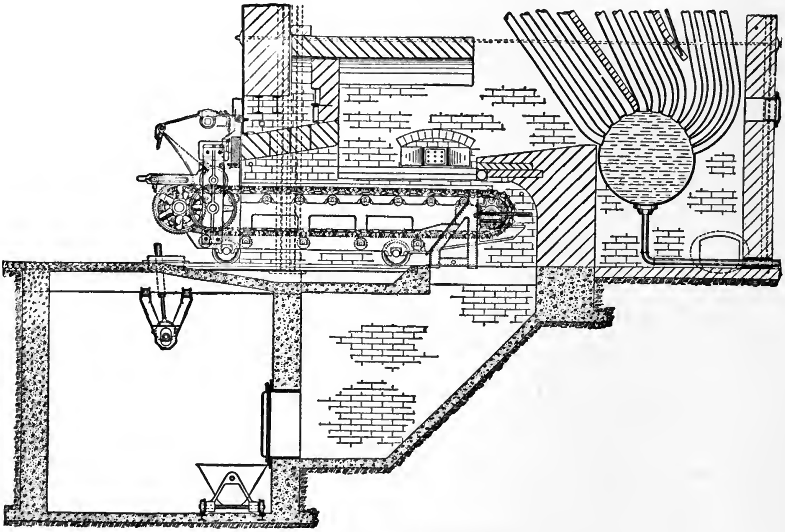


FIG. 28.—Chain-grate stoker.

The chain-grate stoker is best suited for small sizes of free burning, non-caking, and high ash bituminous coals. This type of stoker is not very satisfactory with high-coking, low ash coals on account of the fusing action of the fuel under the fire brick arch.

Inclined Grate Stokers.—The Roney stoker, illustrated in Fig. 29, is representative of the inclined grate over-feed type. It consists of a hopper for receiving the coal, a series of stepped inclined grate bars, which extend across the furnace, and a dumping grate for receiving the ash and clinkers. The grate bars are T-shaped in section and are pivoted near their lower ends. The lower ends of the stepped bars rest in slots cut in the rocker bar. The rocker bar is given a reciprocating motion by a shaft which passes in front of the stoker and which in turn receives its motion from the small steam engine. The coal from the hopper at the front of the stoker first strikes a dead plate, from which it is pushed on to the inclined grate bars. The grate bars oscillate, alternately assuming a horizontal and an inclined position, thus slowly sliding the coal down the grate. As in the case of the chain-grate stoker, the rate of feed can be regulated, and when properly operated the coal should be completely burned when it reaches the dumping grate. As the fuel passes under the fire brick arch, the volatile gases are mixed with heated air, the coal is coked, and smoke is greatly reduced.

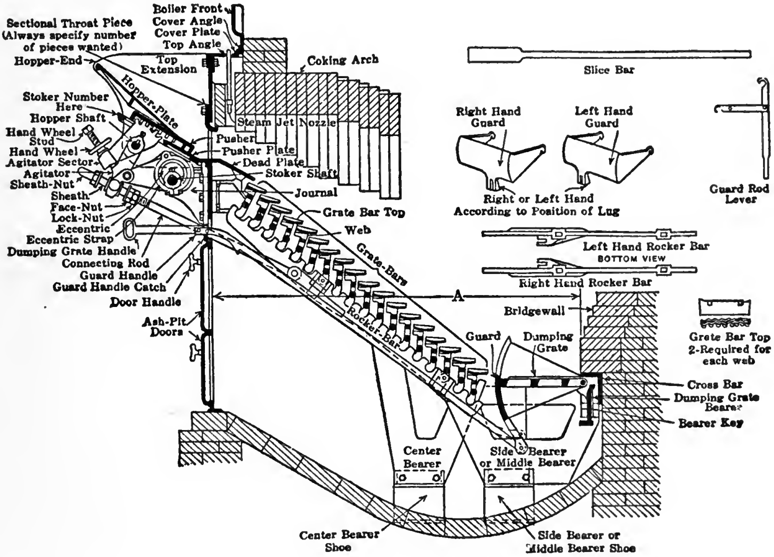


Fig. 29.—Roney stoker.

The Murphy stoker, illustrated in Fig. 30, is of the inclined grate, side feed, type. It consists of a Dutch oven, two coal hoppers, two sets of inclined grates, and a stoking mechanism. The grate bars are installed so that only alternate ones are movable and these are given a motion which moves them above and below the stationary bars. This breaks the adhesion of the coal to the bars and it slowly feeds down the inclined grates. A toothed clinker bar is placed in the bottom of the stoker to break up the clinker.

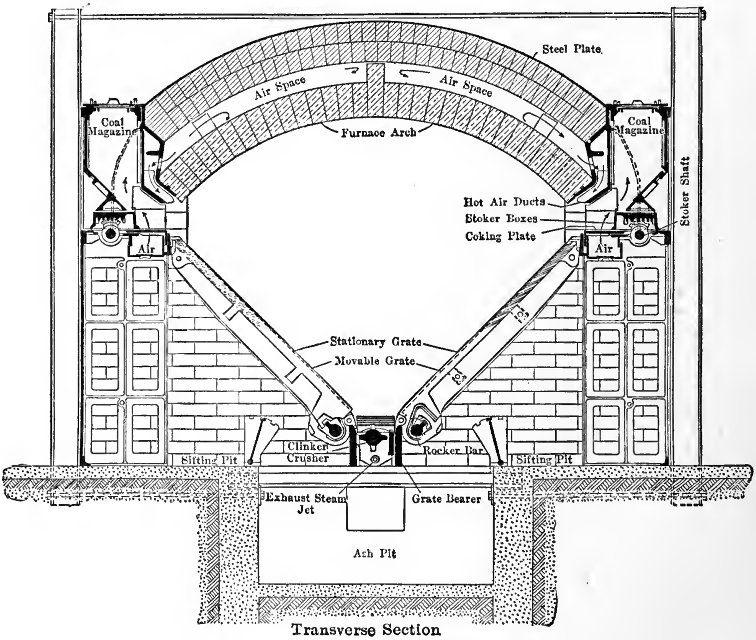


Fig. 30.—Murphy stoker.

Underfeed Stokers.—Fig. 31 illustrates the Jones underfeed stoker. It consists of a retort placed inside the furnace and of an external feeding mechanism. The retort is trough-shaped and along each side are placed tuyere blocks for admitting the air. The feeding mechanism is a steam cylinder in which works a piston. A coal ram is attached to the same piston rod. As the ram forces coal into the retort, the coal already there is forced upward. To prevent the coal from heaping up near the front of the furnace, pusher blocks, connected to the piston rod, are placed in the bottom of the retort. These tend to maintain a level fire.

The operation of this stoker is such that the clinkers and ash are worked to the top of the fire and are removed from the furnace through the fire doors by hand. The green fuel is fed below the burning coal, and the hottest part of the furnace is at the top of the fuel bed. As the burning coal gradually works its way toward the top, any volatile matter is distilled off and is consumed before reaching the furnace.

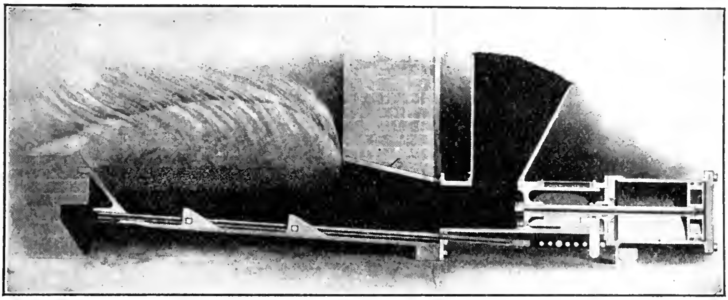


FIG. 31.—Jones stoker.

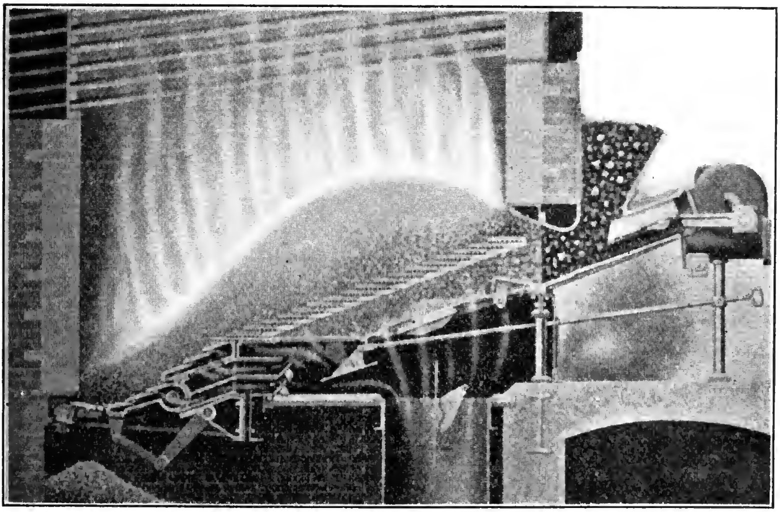


FIG. 32.—Westinghouse Stoker.

Air for the Jones stoker is supplied by a forced draft fan. A duct from the fan leads the air to the stoker where it passes into the furnace through the tuyeres in the retort. This class of stoker has a high forcing capacity and is suitable for coking bituminous coals.

In another type of underfeed stoker, the American, the piston is replaced by a worm, which continuously feeds the coal underneath the fire.

Westinghouse Stoker.—The Westinghouse stoker, illustrated in Fig. 32, combines the principles of the underfeed and of the inclined grate types of stokers. The fuel from the hopper is fed into the upper retort, which is located in the bottom of the coal hopper. A ram in the retort pushes the green fuel outward and beneath the burning fuel, which rests upon an inclined grate. The green fuel being introduced under the fire is slowly coked. The lower ram forces the fuel bed and refuse toward the dump plates at the rear. The stroke of the lower ram can be regulated to suit the load and the fuel. Air for the combustion of the fuel is supplied by a forced draft fan, and enters the fuel bed through openings in the tuyere boxes.

Feed-water Heaters and Economizers

Feed-water Heaters.—If cold water is fed to a boiler, there will be a difference in temperature at the various parts of the boiler shell, and strains will be set up by the unequal expansion and contraction, which will decrease the life of the boiler, besides impairing the tightness of the setting. With hot feed water, strains due to unequal expansion and contraction are reduced. Modern power plants are usually provided with feed-water heaters, which heat the water by exhaust steam. The use of a feed-water heater will increase the economy of a steam power plant by utilizing exhaust steam, which would otherwise be wasted. Under ordinary conditions, heating feed water eleven degrees will produce about one per cent. gain in economy. The capacity of a boiler plant can be increased more cheaply by the installation of a feed-water heater, outside the boiler, than by increasing the size of the boiler. Heating the feed water outside of the boiler serves also to purify the water before it enters the boiler.

Feed water can be heated by live steam, by exhaust steam, or by the waste chimney gases.

The heating of feed water by live steam is not recommended, as no use is made of the waste heat.

Feed-water heaters which utilize the heat of exhaust steam from engines and pumps are most commonly used. Heaters may be constructed so that the exhaust steam and water come into direct contact and the steam gives up its heat by condensation. Such heaters are called open feed-water heaters. One type of open feed-water heater is illustrated in Fig. 33. In this form, water passes over trays upon which the impurities thrown out of the water by the heat are deposited, and can be easily removed. Open feed-water heaters are provided with oil separators through

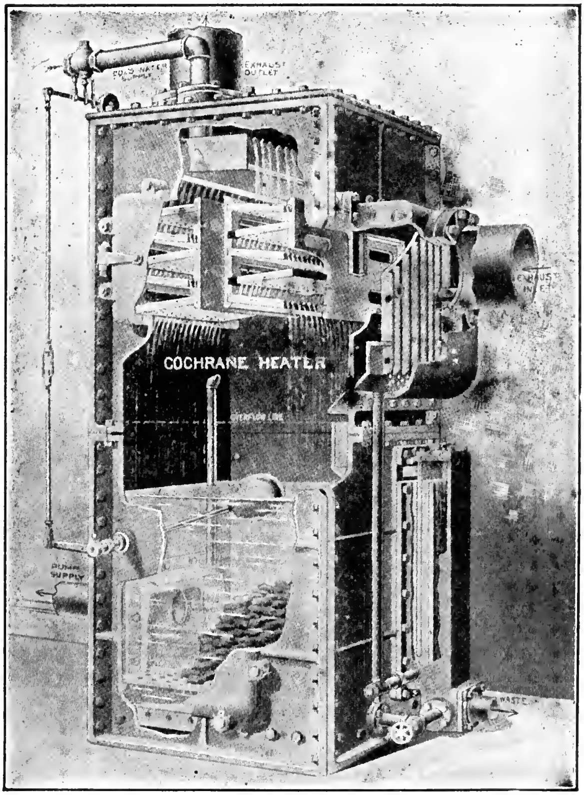


Fig. 33.—Open feed water heater.

which the exhaust steam passes before entering the heater. Open feed-water heaters are usually placed on the suction side of the feed pump and at a higher elevation than the pump cylinders as a feed pump cannot lift hot water.

If it is desired to pass the water through the heater under pressure or to prevent the steam and water from coming into contact with each other, some form of closed heater should be used. Fig. 34 illustrates a heater of this type. Here the steam on one side of the tubes heats the water on the other. Such heaters may be constructed so that either the steam or the water flows through the tubes. Closed feed-water heaters are more expensive than the open types, more difficult to clean, and are used only in special cases.

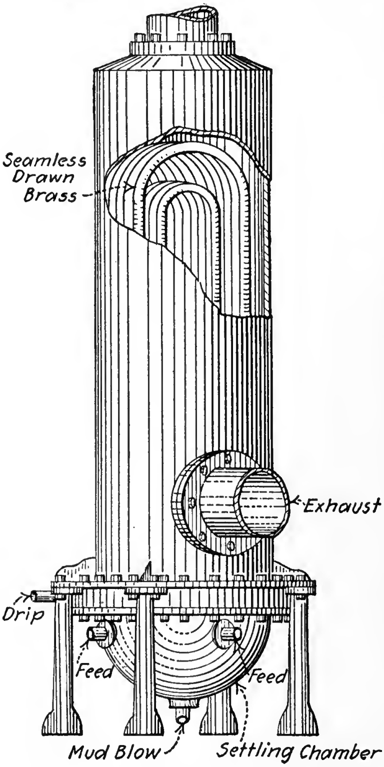


Fig. 34.—Closed feed water heater.

Economizers.—A feed-water heater which derives its heat from the flue gases as they leave the boiler is termed an economizer. Economizers increase the capacity of a boiler plant while providing a means for storing large quantities of hot water.

Fig. 35 illustrates an economizer connected to the boiler. An economizer consists of a series of straight, vertical, cast iron tubes connected at their top and bottom by headers. The boiler feed water enters at the end nearest the chimney, passes through the sections of tubes and is heated by the hot gases that circulate through them.

The economizer is usually installed in such a manner that the gases may be by-passed around the tubes or through them. This provision is made to facilitate repairs without shutting down the boiler.

The tubes of an economizer must be regularly cleaned both internally and externally. The heating of the water within the tubes causes impurities to be deposited, which, if allowed to accumulate, would impair the efficiency of the tubes. Handholes are placed over each tube to facilitate the cleaning of the internal surface. The external surface of the tubes must be freed from soot and moisture, which are deposited from the furnace gases. The cleaning of the external surface of the tubes is accomplished by a mechanical cleaner. Small cast iron scrapers surround each tube and are made to slowly travel the length of the tube. In this manner, any soot deposit which collects upon the surface of the tube may be removed.

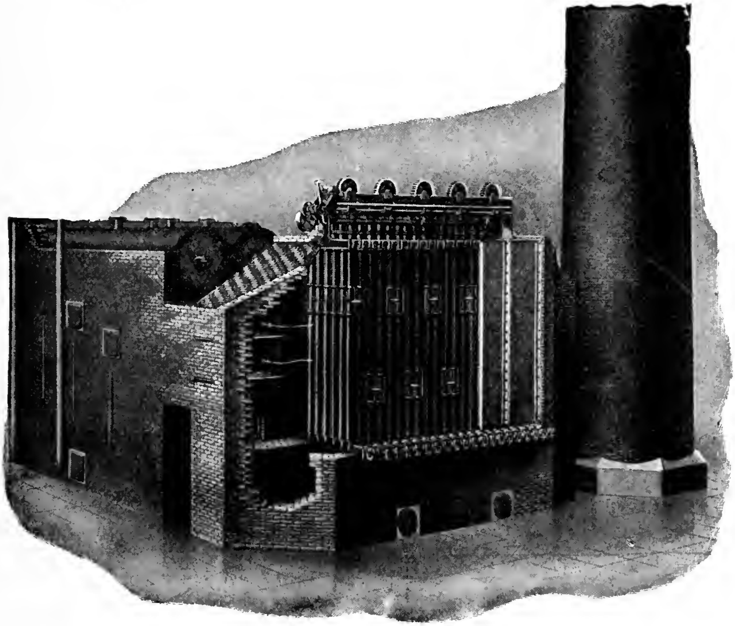


FIG. 35.—Economizer.

It is not considered good practice to have the temperature of the water entering the economizer less than 100°F. Low water temperatures at the inlet to the economizer produce sweating of the first rows of tubes, and may result in the corrosion of the economizer tubes.

An economizer, besides providing a large storage of hot water for sudden demands, increases the economy of a steam power plant by utilizing the heat in the flue gases. The reduction of the flue gas temperature, due to the absorption of heat by the economizer, may necessitate the addition of mechanical draft apparatus, or an increase in the height of the chimney. The purity of the feed water, the sulphur content in the coal, and the cost of producing additional draft should be considered in connection with the installation of economizers. With impure feed water, the cost of keeping the economizer tubes clean may be excessive.

DRAFT PRODUCING EQUIPMENT

Chimneys.—A chimney or stack is used to carry off the obnoxious gases formed during the process of combustion, to discharge them at such an elevation as will render the gases unobjectionable, and to create sufficient draft to cause fresh air, carrying oxygen, to pass through the fuel bed, producing continuous combustion. The majority of power plants depend upon chimneys for draft.

The draft produced by a chimney is due to the fact that the hot gases inside the chimney are lighter than the outside cold air. In the boiler plant, the cold air is heated in passing through the fuel bed, rises through the chimney, and is replaced by cold air entering under the grate. This means that the amount of draft produced by a chimney depends upon the flue gas temperature.

The intensity of the draft produced by a chimney depends also on its height; the taller the chimney, the greater is the draft produced, since the difference in weight between the column of the air inside and that of the air outside increases as the height of the chimney.

The intensity of chimney draft is measured in inches of water, which means that the draft is strong enough to support a column of water of the height given. The draft produced by chimneys is usually one-half to three-fourths of an inch of water.

Chimneys are made of steel, brick, or reinforced concrete. For small plants steel stacks are most desirable on account of lower first cost and ease of construction and erection. Self-sustaining steel stacks are used in some large power plants on account of the smaller space required as compared with other stacks. Steel stacks will rust and corrode unless they are kept well painted.

Brick is most commonly used where permanent chimneys are desired. A brick chimney, unless carefully constructed, will allow large quantities of air to leak in, which will interfere with the intensity of the draft. Brick chimneys are built round, octagonal, or square, and are usually constructed with two walls and an air space between them. The inside wall is lined with fire-brick. In some cases chimneys are built of hard burned brick and without lining. The thickness of the chimney wall decreases by a series of steps, as illustrated in Fig. 36.

The use of concrete chimneys, reinforced with steel rods, is increasing on account of the absence of joints, light weight, and space economy as compared with brick chimneys. Ordinarily a reinforced concrete chimney is less expensive to build than a brick chimney.

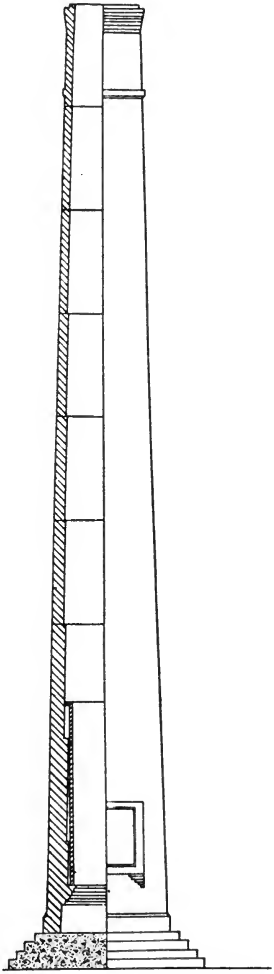


FIG. 36.—Brick chimney.

Draft produced by chimneys is called natural draft, and varies as the square root of the height. The approximate boiler horse-power a chimney will serve can be determined by the following formula, in which A is the internal sectional area of the chimney in square feet, and H is its height above the grate in feet:

$$\text{Boiler Horsepower} = 3.33\,(A - 0.6\sqrt{A})\,\sqrt{H}.$$

Artificial Draft.—In large power plants equipped with mechanical stokers or economizers, the draft produced by chimneys is insufficient and some artificial method has to be used. A chimney once built is limited in capacity and will seldom be capable of producing a draft greater than 0.75 inches of water, or about 0.43 ounces pressure. Draft produced by a fan may have a large range of pressures, depending upon the speed at which it is operated.

Artificial draft may be produced by steam jets. In some cases the jets discharge beneath the grates, forcing the air and steam up through the fuel bed. In locomotives the jets of steam from the engine exhaust are directed upward from the base of the stack. Steam jets beneath the grates are cheap to install and with certain varieties of coal are absolutely necessary in order to prevent the formation of clinkers. Steam jets are uneconomical, and in stationary practice preference is given to the fan or the blower systems of artificial draft.

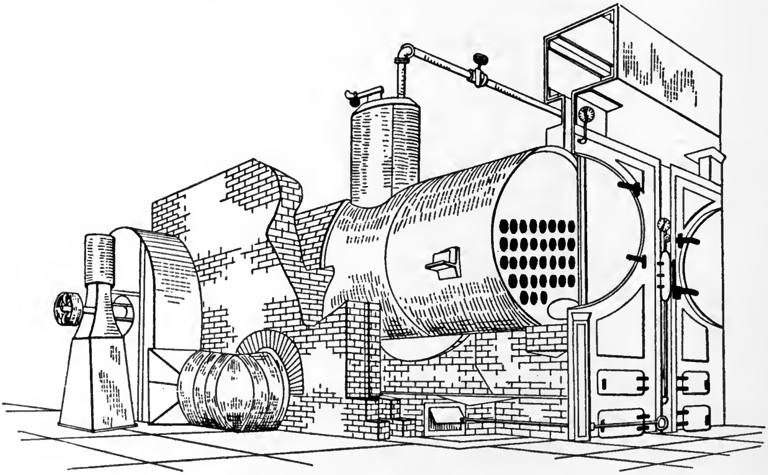


Fig. 37.—Forced-draft system.

The method by which the fan produces draft gives rise to the forced and induced draft systems.

In the forced system, Fig. 37, the air delivered to the furnace is usually taken from the boiler room, and a duct from the fan discharges it into the ash pit. The air is thus forced into the furnace, which is under a slight pressure. The fact that the pressure within the furnace is greater than that of the atmosphere is one of the objections to the forced draft system. It may cause the gas to leak into the boiler room through the cracks in the setting, and the flames from the furnace to flare out when the fire doors are opened. To overcome this latter objection, the system must be equipped with suitable dampers for shutting off the air when the furnace doors are opened.

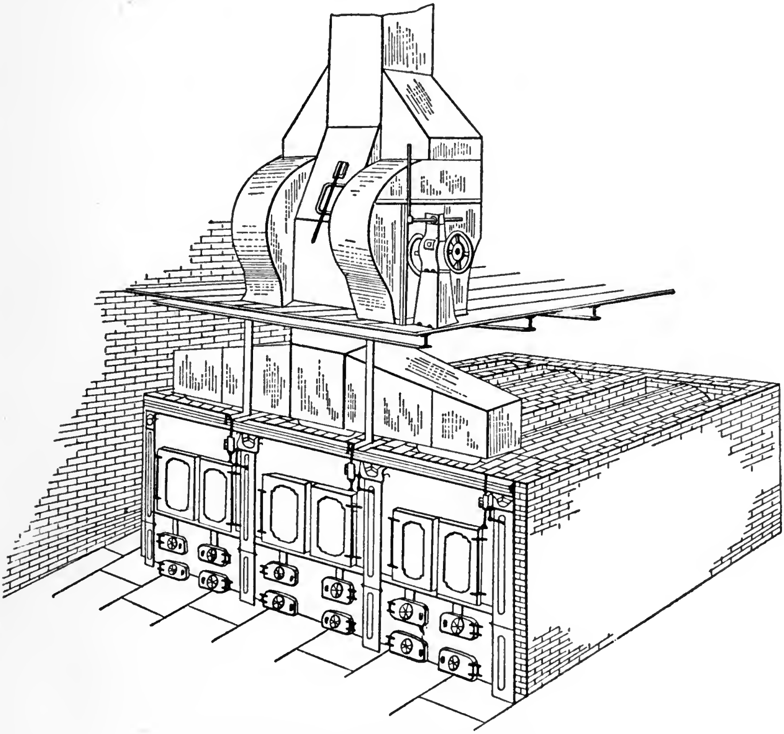


Fig. 38.—Induced-draft system.

The forced draft system lends itself well to old plants, when the draft produced by chimneys becomes insufficient on account of increased demands for power. The forced draft system is also used in connection with the underfeed types of stokers.

In the induced draft system, Fig. 38, the suction side of the fan is connected with the breeching of the boiler, and the products of combustion are discharged through a short chimney. The breeching is usually provided with a by-pass direct to the stack to be used in case of accident to the fan. The furnace and ash pit, in the case of the induced draft system, are under a slight vacuum, any tendency for air leakage being inward.

Since the induced draft fan handles gases at temperatures of 400 to 500 degrees F., it must be much larger than a forced draft fan delivering cold air. This means that the cost of the induced draft system is greater than that of the forced draft system for the same size power plant.

The induced draft system is generally installed with economizers and is also used extensively in large steam-electric power plants which have high peak loads.

Mechanical draft permits a higher rate of combustion with less air per pound of fuel than is possible with natural draft produced by chimneys. A forced draft system for a large power plant will cost about one-third that of a brick chimney. Induced draft system will cost from 40 to 60 per cent. less than a brick chimney. To offset the above advantages is the cost of operating the mechanical draft system. The power required to operate a fan will amount to from 2 to 5 per cent. of the total boiler steaming capacity. The mechanical draft systems have also greater depreciation and maintenance costs than well constructed chimneys.

FEED PUMPS AND INJECTORS

Water is forced into steam boilers by pumps or injectors. A pump will handle water at any temperature, while an injector can be used only when the water is cold. The injector is not as wasteful of steam as a pump and for feeding cold water has the additional advantage that it heats the water while feeding it to the boiler.

Feed Pumps.—Feed pumps may be driven from the cross-head of an engine. Such pumps are very simple, but can only supply water to the boiler when the engine is in operation.

Direct acting steam pumps, driven by their own steam cylinders, are most commonly used for feeding stationary boilers, as they can be operated independently of the main engine and their speed can be regulated to suit the feed water demand of the boilers. With a tight suction pipe a direct-acting pump will lift cold water about 15 feet. Centrifugal pumps are frequently used in large power plants and are generally driven by steam turbines.

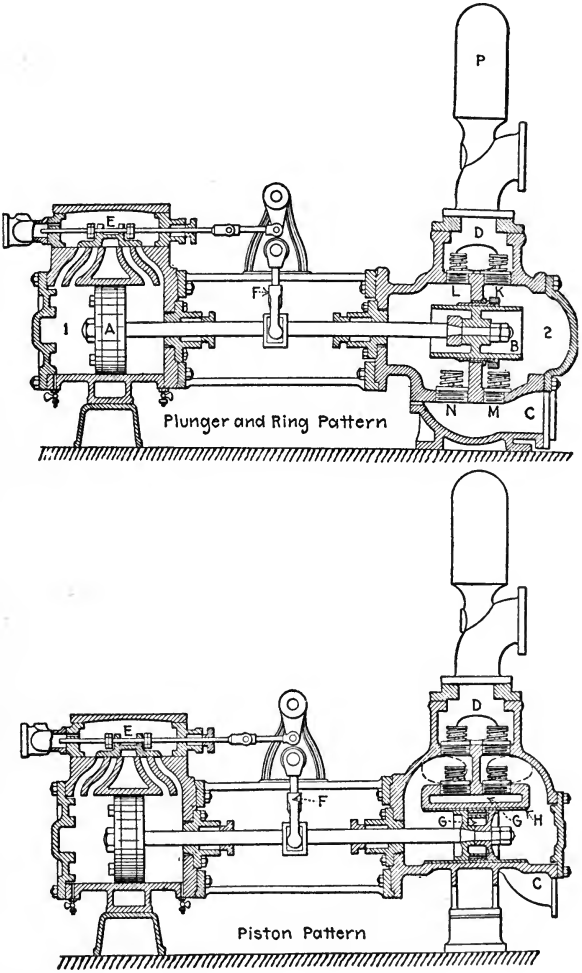


Fig. 39.—Boiler feed pumps.

The details of construction of two forms of direct-acting pumps are shown in Fig. 39. The essential difference between these pumps is that one uses a piston and the other a plunger. Both types are extensively used. The piston pattern occupies less floor space, but is more difficult to pack.

In the pump shown in Fig. 39, 1 is the steam cylinder and 2 is the water cylinder. The valve *E* is moved by the vibrating arm *F*, and admits steam into the cylinder, 1. If steam is admitted at the left of the piston *A*, the piston will be moved to the right, pushing the plunger *B*, driving the water through the valve *K*, and into the feed line at *O*. While the plunger is moving to the right, a partial vacuum is formed at its left which action opens the valve *N* and draws the water from the supply at *C*. When the plunger *B* reaches the extreme position to the right, the vibrating arm *F* moves the valve *E* to the left, admitting steam which pushes the piston and plunger to the left, driving the water through the valve *L* and taking a new supply through *M*. The function of the air chamber *P* is to secure a steady flow of water

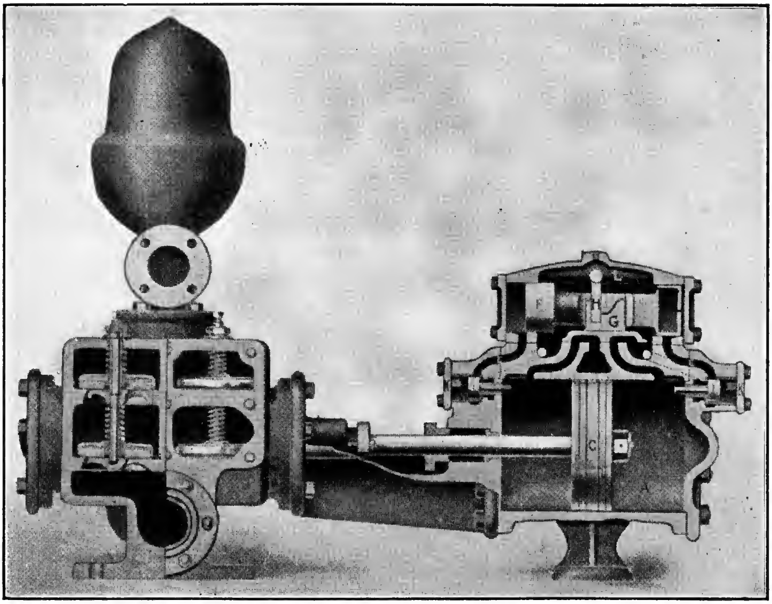


FIG. 40.—Boiler feed pump.

through the discharge and to prevent excessive pounding at high speeds by providing a cushion for the water.

The pump shown in Fig. 40 differs from the one just described in that the steam valve *G* is operated by the steam in the steam chest and not by a vibrating arm outside of the cylinder. The piston *C* is driven by steam admitted under the slide valve *G*, this valve being moved by a plunger *F*. This plunger *F* is hollow at the ends and the space between it and the head of the steam chest is filled with steam. Thus the plunger remains motionless until the piston *C* strikes one of the valves *I*, exhausting the steam through the port *E* at one end. The water end is similar to that of the pump in Fig. 39.

Injectors.—Injectors are used very commonly for the feeding of locomotive, portable, and small stationary boilers. In some power plants injectors are used in conjunction with pumps as an auxiliary method of feeding boilers.

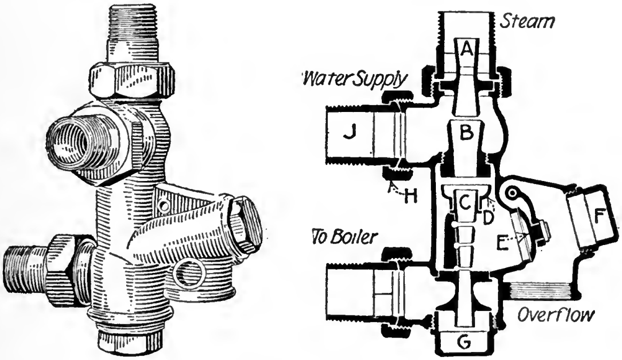


Fig. 41.—Injector.

The general construction of an injector is illustrated in Fig. 41. Steam from the boiler enters the injector nozzle at *A*, flows through the combining tube *BC*, and out to the atmosphere through the check valve *E* and overflow. The steam in expanding through the nozzle *A* attains considerable velocity, and forms sufficient vacuum to cause the water to rise to the injector. The steam jet at a high velocity coming into contact with the water is condensed, gives up its heat to the water, and imparts a momentum which is great enough to force the water into the boiler against a steam pressure equal to or greater than that of the steam entering the injector.

As soon as a vacuum is established in the injector and the water begins to be delivered to the boiler, the check valve *E* at the overflow closes. Should the flow of feed water to the boiler be interrupted, due to air leaking into the injector or to some other cause, the overflow will open and the steam will escape to the atmosphere.

Due to the fact that the vacuum in an injector is broken as the temperature of the water increases, injectors can work only when the feed water is 150°F. or cooler.

Duty of Pumps.—The duty of a pump is measured in foot pounds of work done in moving water for each 1,000 pounds of steam used, or for each million British thermal units delivered in the steam.

Duty per million B.t.u. is:

$$\frac{\text{Water horsepower} \times 1{,}980{,}000 \times 1{,}000{,}000.}{\text{B.t.u. in steam used per hour}}$$

Small direct-acting pumps have duties as low as 15,000 foot pounds per 1,000 pounds of steam used. Large pumping engines have shown results as high as 181,000,000 foot pounds per 1,000 pounds of steam.

GRATES FOR BOILER FURNACES

Grates are formed of cast iron bars. Several forms of grate bars are illustrated in Figs. 42 and 43. Plain grates (*b*), Fig. 42, are best adapted for caking coals and are usually provided with iron bars, cast in pairs, and with lugs at the side. The Tupper type of grate (*c*) Fig. 42, is more suitable for the burning of hard coal, which does not cake. The grates of a boiler furnace

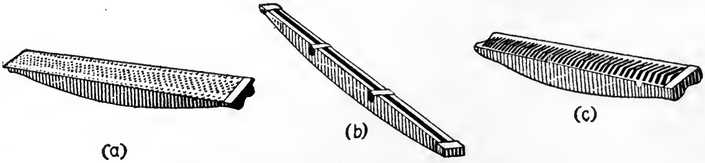


FIG. 42.—Grate bars.

can be easily inter-changed to suit the fuel burned. For most economical results some form of rocking and dumping grate, as shown in Fig. 43, should be used.

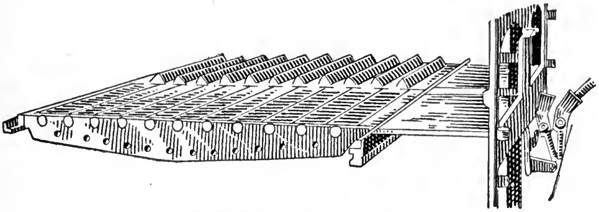


FIG. 43.—Dumping grate.

COAL AND ASH HANDLING SYSTEMS

In small power plants the coal is delivered to the furnace and the refuse is removed from the ash pit by hand shoveling. In such cases the coal pockets or coal bunkers should be located opposite the boilers, so that the rehandling of coal is reduced to a minimum. If the coal cannot be stored in front of the boilers, coal tip-carts are found very satisfactory for conveying the fuel to the boiler room.

As plants increase in size, mechanical coal and ash handling systems are warranted. The coal handling system usually consists of the following equipment: a receiving hopper, into which the coal is delivered; a crusher, which reduces the fuel to such a size as can conveniently be handled by stokers; elevating and conveying systems for raising the coal from the crusher and for distributing it to the bunkers, which are placed over the boilers; and spouts which deliver the fuel from the bunkers to the stokers.

The endless chain bucket conveyor is frequently used for handling both coal and ashes. This system consists of a continuous series of buckets suspended between two endless chains. The discharge of the coal from the buckets into the bunkers over the boilers is effected by a tripping device which turns the buckets over. The buckets pass beneath ash hoppers under the boilers. The ashes are elevated by the buckets and discharged into an ash storage bin. Hoist and trolley systems, scraper conveyors, screw conveyors, and belt conveyors are also used in handling coal and ashes. Vacuum or steam conveyors are used for handling ashes and fine coal. Vacuum and steam conveying systems consist of a pipe line through which the ashes or fine coal are carried by air or steam at high velocity.

Problems

1. Discuss the advantages of superheaters for large power plants.
2. Report on the uses of mechanical stokers in the power plants in your vicinity.
3. Give complete directions for the handling of an underfeed mechanical stoker.
4. Calculate the per cent. gain which will result from preheating feed water to 200°F., from a temperature of 70°F., if a boiler plant is operated at a steam pressure of 140 pound gage.
5. Examine the draft producing systems in the power plants in your vicinity, and hand in a complete report, showing types of stacks, mechanical draft systems, and the intensity of the draft used.
6. A pumping engine pumps 8,000,000 gallon of water per day of twenty-four hours, against a head of 110 feet. It uses 2,500 pounds of steam per hour. If the steam pressure is 140 pounds per square inch gage, and the feed water temperature is 202°F., calculate the duty of the pumping engine per million B.t.u.

CHAPTER VI

PIPING AND BOILER ROOM ACCESSORIES

Grades and Sizes of Piping.—Piping used to convey the steam generated in a boiler is made of wrought iron or of mild steel. Wrought iron pipe is superior to steel pipe, as it is softer, is easier to thread, and is not subject to corrosion. Wrought iron pipe is more expensive and more difficult to secure than steel pipe. The largest portion of piping used in power plants is of mild steel, lap or butt welded for high pressures. Cast steel pipe has been found more suitable for superheated steam than mild steel pipe.

Sizes of standard steam pipe up to 12 inches are named by their inside diameter; above 12 inches they are designated by their outside diameter. The sizes of boiler tubes are given by their outside diameter.

Standard steam pipe is made in sizes of 1/8, 1/4, 3/8, 1/2, 3/4, 1, 1 1/4, 1 1/2, 2, 2 1/2, 3, 3 1/2, 4, 4 1/2, 5, 6, 7, 8, 9, 10, 11, and 12 inches. Standard pipe is suitable for pressures up to 125 pounds per square inch.

The various grades of pipe are: standard, extra heavy, and double extra heavy. Extra heavy and double extra heavy have the same outside diameter as standard pipe, but the inside diameters are smaller, due to the greater thickness of the pipe. Extra heavy pipe is suitable for pressures up to 250 pounds per square inch, while double extra heavy pipe can be used for pressures up to about 1,000 pounds per square inch.

Pipe Fittings.—Two kinds of fittings are used in steam power plants, the screwed and the flanged fittings. For saturated steam and for pressures less than 150 pounds, all fittings 3 1/2 inches and under may be screwed. Fittings 4 inches and over should have flanged ends. Screwed fittings, when properly installed, are less liable to leak than flanged fittings, which are put together with gaskets. Flanged fittings are easily taken apart and are most generally used in modern power plants.

The pipe fittings most commonly used are illustrated in Figs. 44 to 52.

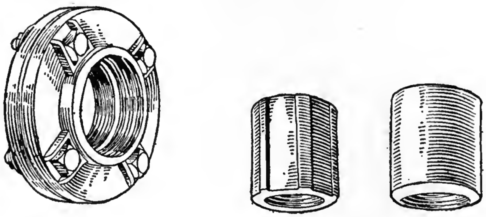


Fig. 44.—Pipe unions and couplings.

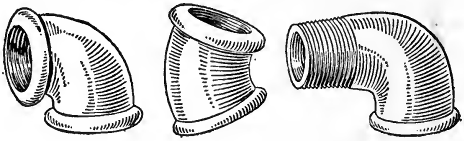


Fig. 45.—Ells.

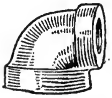


Fig. 46.—Reducing ell.

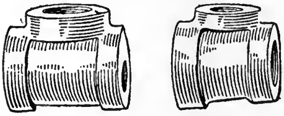


Fig. 47.—Tees.

Fig. 48.—Cross.

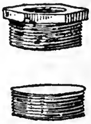


Fig. 49.—Bushing.

Fig. 50.—Reducer.

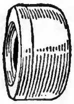


Fig. 51.—Cap.

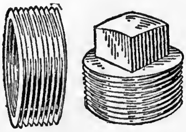


Fig. 52.—Plug.

Fig. 44 illustrates several forms of pipe unions and couplings, which are used for uniting two lengths of pipe.

The elbow or ell shown in Fig. 45 is employed for connecting two pipes, of the same size, at an angle to each other. If the pipes are of different diameters a reducing ell, as shown in Fig. 46, should be used.

The tee shown in Fig. 47 is used for making a branch at right angles to a pipe line.

The cross shown in Fig. 48 is used when two branches must be connected in opposite directions.

In order to reduce the size of a pipe line, a bushing, Fig. 49, or a reducer, Fig. 50, can be used.

To close the end of a pipe, a cap, Fig. 51, is used, while the plug shown in Fig. 52, is used to close a fitting threaded on the inside.

In cast iron flanged fittings the flange is always a part of the casting. For joining two ends of a pipe, the pipe and flange are threaded, the pipe is screwed beyond the face of the flange, and the two are faced off together. Another method is to weld the flanges on the pipe.

Expansion of Piping.—In piping systems, provision must be made to allow for the expansion and contraction due to variation in the temperature of the steam within the pipe. Unless a pipe expands freely, distortion or injurious strains on the joints and fittings will occur.

The simplest method is to permit the expansion to adjust itself in a threaded joint. Such an arrangement is shown in Fig. 53. Any expansion or contraction in the piping is adjusted by a slight movement in the screwed joints.

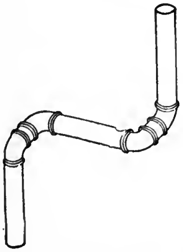


FIG. 53.—Double-swing expansion joint.

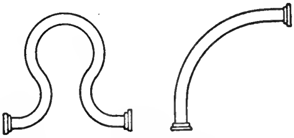


FIG. 54.—Long radius bends.

Another method quite extensively used in high pressure piping is to insert a long radius bend, as illustrated in Fig. 54. A long radius bend, besides taking care of the expansion after the piping is in place, reduces the number of joints, decreases friction, and is much easier to erect than pipe fittings. One of the objections against the use of long radius bends is the space required.

The slip expansion joint illustrated in Fig. 55 overcomes the above objection. The main casting of this expansion joint is divided into two parts. The expansion or moving element consists of a non-corrodible bronze sleeve, made steam tight by the long stuffing box. The sleeve is supported at the outer end by flanges. In installing a slip expansion joint, the pipe must be securely anchored to prevent the steam pressure from forcing the joint apart.

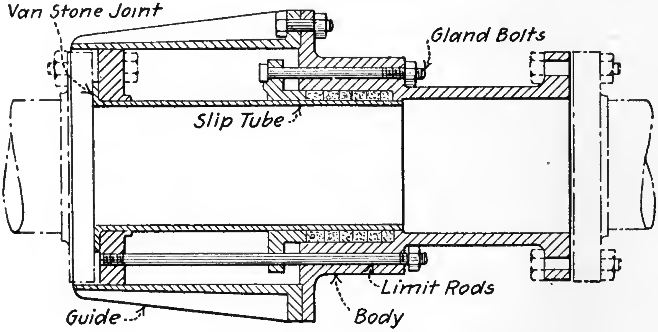


FIG. 55.—Expansion joint.

Pipe Covering.—All pipes carrying steam and hot water should be covered with some heat insulating material in order to reduce the loss of heat to a minimum. If saturated steam, is conveyed in uncovered steam pipes, some of it will condense, reducing the economy of the plant. Tests demonstrate that pipe covering will pay for itself in a very short time.

Pipe covering is usually applied in sections, molded to the required size of the pipe and secured to the pipe by bands. Valves and fittings are usually covered with a plastic insulating mortar.

Erecting Pipe.—Steam pipe lines should always be laid with a gradual slope in the direction in which the steam flows. This will allow the condensation and the steam to flow in the same direction. If this is not done water may accumulate, will be picked up by the steam, and may cause much damage either to the fittings or to the engine.

Care must be taken that the pipe lines have the proper alignment in order to prevent strain on the fittings. Pipe lines must be supported by wall brackets, hangers, or floor stands to guard against excessive deflection and vibration.

Valves.—The function of a valve is to control and regulate the flow of water, steam, or gas in a pipe. In the globe valve, Fig. 56, the fluid usually enters at the right, passes under the valve, and out at the left. This method of installation permits the valve stem to be packed, when the valve is closed, without cutting the steam pressure off the entire line.

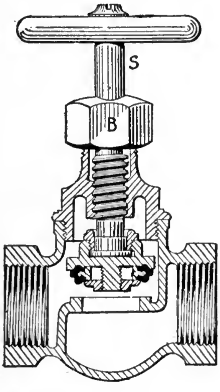


Fig. 56.—Globe valve.

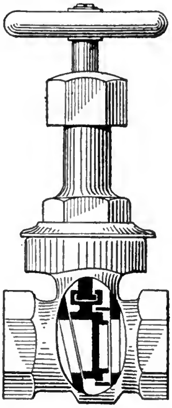


Fig. 57.—Gate valve.

If a globe valve is installed so that the fluid enters at the left, Fig. 56, the pressure of the steam, when the valve is closed, tends to keep it in that position and there is much less likelihood of the valve leaking, but the valve cannot be opened if it should become detached from the stem.

Globe valves in sizes up to three inches have brass bodies; large valves are made of cast iron for ordinary pressures and temperatures, and of cast steel for high temperatures and pressures.

A gate valve is shown in Fig. 57. This form of valve gives a straight passage through the valve, and is preferable for most purposes to the globe valve. For high pressure work and in large sizes, gate valves are usually of the outside screw type, which means that the stem protrudes beyond the hand wheel. This enables the operator to tell at a glance whether the valve is open or closed. The gate valve illustrated in Fig. 57 is of the inside screw type, and is used in small sizes and also in plants where the screw must be protected from dirt.

Fig. 58 illustrates an angle valve which takes the place of an ordinary valve and ell.

The function of a check valve, illustrated in Fig. 59, is to allow water or steam to pass in one direction but not in the other. A boiler feed line should always be provided with a check valve and also with some form of globe or gate valve to enable the operator to examine and repair the check valve.

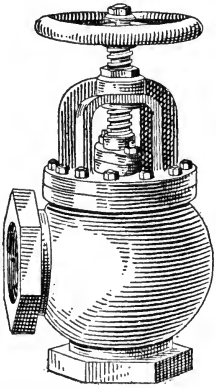


Fig. 58.—Angle valve.

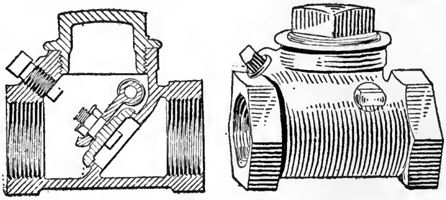


Fig. 59.—Check valve.

Blow-off Valves.—A boiler should always be provided with a blow-off connection at its lowest point for removing mud and sediment, as well as for the purpose of draining the boiler. The blow-off connections must be provided with blow-off valves, which can be easily opened, which will give a free passage for scale and sediment when open, and which will not leak when closed. Best practice recommends the use of two valves or of a valve and a blow-off cock in the blow-off line of each boiler.

Safety Valves.—The function of a safety valve is to prevent the steam pressure from rising to a dangerous point. The two common forms of safety valves are: the lever safety valve and the spring or pop safety valve.

The lever safety valve shown in Fig. 60 consists of a valve disc which is held down on the valve seat by means of a weight acting through a lever, the steam pressing against the bottom of the disc.

The lever is pivoted at one end to the valve casing, and is marked at a number of points with the pressures at which the boiler will blow off if the weight is placed at that particular point. Lever safety valves are seldom used in modern power plants.

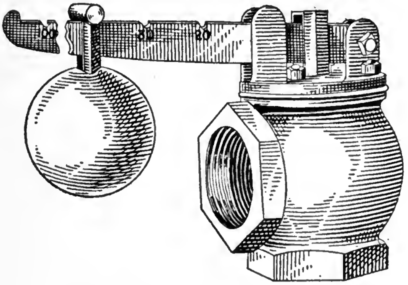


Fig. 60.—Lever safety valve.

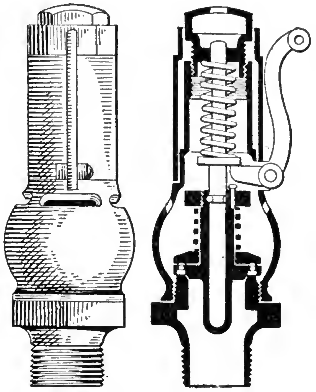


Fig. 61.—Pop safety valve.

The pop safety valve shown in Fig. 61 differs from the lever valve in that the valve disc is held on its seat and the steam pressure is resisted by a spring, in place of a weight and levers Pop safety valves can be adjusted to blow off at various pressure. by tightening or loosening the spring pressure on the valve disc.

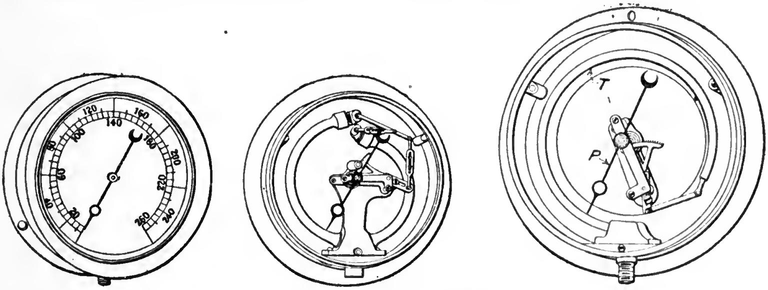


Fig. 62.—Steam gages.

The American Society of Mechanical Engineers recommends that two or more safety valves be installed on every boiler, except in the case of small boilers which require a safety valve 3 inches or smaller.

Steam Gages.—A steam gage indicates the pressure of the steam in a boiler. The most common form, shown in Fig. 62, consists of a curved spring tube closed at one end. One end of the tube is free, while the other is fastened to the fitting which is secured into the space where the pressure is to be measured. The cross section of the tube is made elliptical or irregular in shape so that pressure applied to the inside of the tube causes the free end to move. This motion is communicated by means of levers and small gears to the needle which moves over a graduated dial face, and records the pressure directly in pounds per square inch.

Water Glass and Gage Cocks.—The height of the water level in a boiler is indicated by a water glass, one end of which is connected to the steam space and the other end to the water space in the boiler. All boilers should also be provided with three gage cocks, one of which is set at the desired water level, one above it and one below. These are more reliable than the water glass and should be used for checking the glass.

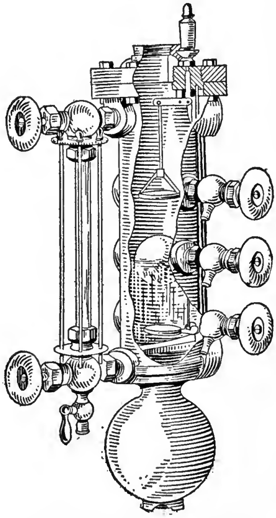


Fig. 63.—Water column.

Water Column.—The steam gage, water glass, and gage cocks are usually fastened to a casting called a water column. One form of water column is shown in Fig. 63. This water column is fitted with a float and a whistle to notify the operator should the water in the boiler become too low or too high. An operator who takes proper care of the boilers in his charge will never allow the water to be at a height that will necessitate audible warnings.

Steam Traps.—The object of a steam trap is to drain the water from pipe lines without allowing the steam to escape. One form of steam trap is shown in Fig. 64; in this case the valve is controlled by a float when the water in the trap rises to a sufficient height. In another type of trap, called the bucket type, there is a bucket in the interior of the trap, which when filled with the condensed steam operates as a float and opens a valve.

Traps which receive the condensed steam and return it to the boiler are called return traps.

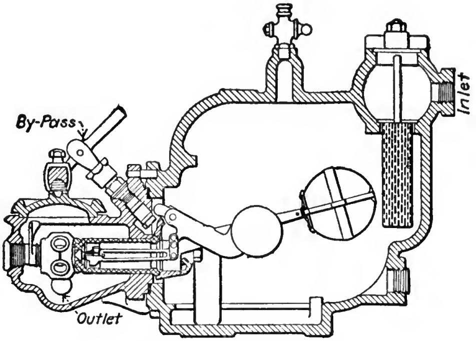


Fig. 64.—Steam trap.

Fusible Plugs.—Plugs with a core of some fusible metal are used to protect boilers from overheating. If a plate, into which a fusible plug is screwed, becomes overheated, the fusible metal melts and runs out allowing the steam and hot water to run into the boiler furnace.

Fusible plugs are placed about three inches above the top row of tubes in a cylindrical tubular boiler and in the lower side of the upper drum of a water tube boiler.

Problems

1. Make a clear sketch showing the location of the boiler stop valve with reference to the piping from the boiler.

2. Make an inspection of some plant in your vicinity and report on the following:

(*a*) Types of fittings used.

(*b*) Are the steam pipes covered? If so, with what material.

3. Make a clear sketch showing how you would arrange the piping and fittings in connection with a boiler blow-off connection.

4. Where should safety valves be placed on fire tube boilers? On water tube boilers?

5. Sketch three (3) forms of pipe supports.

6. Why place a fusible plug about three inches above the top row of tubes in a cylindrical tubular boiler?

CHAPTER VII

STEAM ENGINES

Description of the Steam Engine.—A steam engine is a motor which utilizes the energy of steam. It consists essentially of a piston and cylinder with valves to admit and to exhaust the steam, a governor for regulating the speed, some lubricating system for reducing friction, and stuffing boxes for preventing steam leakage.

In the steam engine working as a motor, continuous rotary motion of the shaft is essential. This is accomplished by the interposition of a mechanism consisting of a connecting rod and crank, which changes the to-and-fro, or reciprocating motion, of the piston into mechanical rotation at the shaft. A steam engine in which the reciprocating motion of the piston is changed into rotary motion at the crank is called a reciprocating steam engine to differentiate it from the steam turbine to be described in a later chapter.

The various parts of a steam engine are illustrated in Figs. 65, 66 and 67.

Steam from the boiler at high pressure enters the steam chest *A*, Fig. 65, and is admitted alternately through the ports *BB* to either end of the cylinder by the valve *C*. The same valve also releases and exhausts the steam used in pushing the piston *D*. *E* is the cylinder in which the steam is expanded. The motion of the piston *D*, Fig. 66, is transmitted through the piston rod *F* to the crosshead *G*, and through the connecting rod *H* to the crank *I*, which is keyed to the shaft *K*.

The shaft is connected directly, or by means of intermediate connectors, such as belts or chains, to the machines to be driven.

The shaft carries the flywheel *L* (Fig. 66), the function of which is to make the rate of rotation as uniform as possible and to carry the engine over the dead-centers. The dead-center occurs when the crank and connecting rod are in a straight line at either end of the stroke, at which time the steam acting on the piston will not turn the crank. A flywheel is sometimes used as a driving pulley, as shown in Fig. 67.

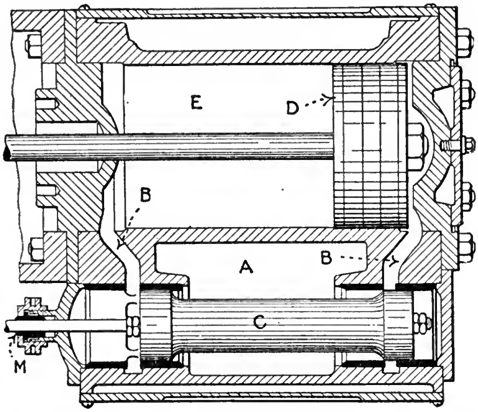


Fig. 65.—Engine cylinder and steam chest.

The eccentric shown in Fig. 67 also rotates with the shaft, and its function is to impart a reciprocating motion to the valve. The eccentric consists of a circular iron disk, so keyed to the shaft that its center is eccentric to the center of the shaft. Around the eccentric fits a ring, called the eccentric strap. The eccentric strap is bolted to a rod, called the eccentric rod. The eccen-

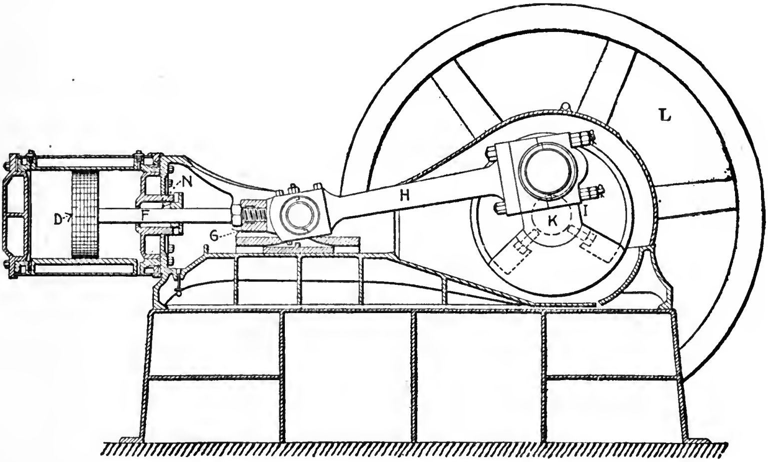


Fig. 66.—Steam engine.

tric imparts a backward and forward motion to the valve through the eccentric rod and valve stem. This motion given to the valve is dependent upon the eccentricity of the eccentric. The eccentricity is the distance between the center of the eccentric and the center of the shaft. Changing the eccentricity changes the travel of the valve. The travel of the valve, or the total distance it moves, is equal to the throw of the eccentric, or to twice the eccentricity.

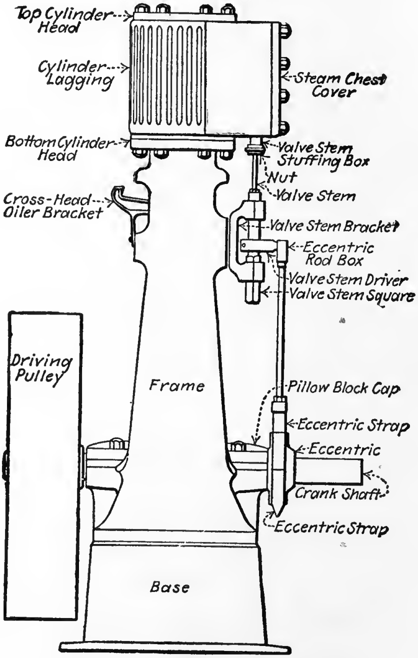


Fig. 67.—Vertical steam engine.

Stuffing boxes which prevent the escape of steam around the rods are illustrated at *M* and *N* in Figs. 65 and 66 respectively.

Early History of the Steam Engine.—The use of steam for the pumping of water dates back to about 1700. The operation of the engines of that time differed from the modern steam engine in that steam was admitted into a closed vessel, at atmospheric pressure, and was condensed by throwing cold water over the external surface of that vessel. The vacuum thus created was utilized in the production of work.

The Newcomen engine of 1705 first made use of a cylinder and piston, but worked on the same principle as the engines mentioned above.

In 1712 Newcomen designed a steam engine in which the condensation of the steam was affected by introducing water into the cylinder. The operation of the valves in the Newcomen engine was by hand and steam at only atmospheric pressure was utilized.

In 1718 Henry Brighton invented a self-acting machine. The valves consisted of a series of tappets operated by the beam of the engine.

James Watt in 1769 laid the foundation for the modern steam engine. His greatest improvements consisted in transferring the steam to another vessel for condensation, making use of pressure greater than atmospheric, constructing the steam engine double-acting, and in inventing the steam engine indicator. Watt was the first to realize the advantages resulting from using steam expansively, although this was applied to an actual engine by Wolfe in 1804.

Losses in Steam Engines.—The main losses in a steam engine are:

1. Loss in pressure as the steam is transferred from the steam boiler to the engine cylinder, due to the throttling action in the steam pipe and ports. Steam in passing through a small port loses part of its energy in overcoming friction. To reduce such losses to a minimum, the pipes and ports must be ample and all steam passages must be as straight as possible.

2. Leakage past piston and valves. The losses due to leakage past the piston and valves are usually very small in well designed engines and may be kept so by proper attention.

3. Loss due to the condensation of the steam in the cylinder. This loss takes place when the entering steam comes in contact with the cylinder walls, which have been cooled by the exhaust steam which previously filled the cylinder. Cylinder condensation becomes greater as the difference between the admission and exhaust pressures is increased. When steam is sufficiently superheated, no condensation takes place, but the loss, though somewhat lessened, is still present.

Losses due to condensation of steam within the cylinder can also be decreased by increasing the engine speed, by regulating the point of cut-off, by compounding, using steam jackets, increasing the size of the units, or by employing the uniflow principle, to be described later.

4. Radiation losses. Radiation losses take place when the steam passes through the steam pipes from the boiler to the cylinder and also while the steam is in the cylinder. Radiation losses in the steam pipes leading from the boiler to the engines can be reduced by the use of a good pipe covering. The radiation losses from the cylinder of the engine are reduced by jacketing the cylinder with some non-conducting material.

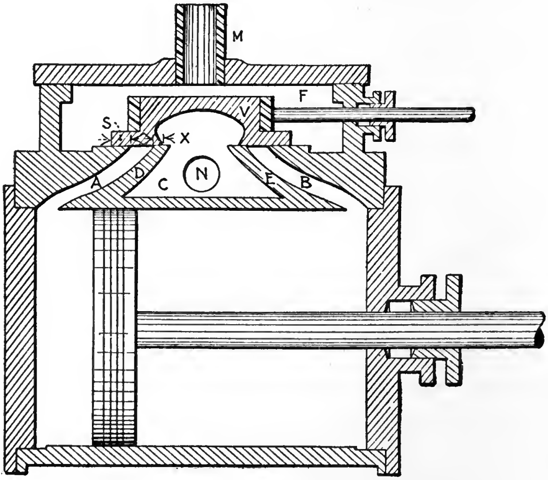


Fig. 68.— Engine cylinder and plain slide valve.

5. Losses of heat in the exhaust steam. Seventy-five per cent. or more of the heat available in the steam when it enters the engine cylinder is carried away in the exhaust. Part of this heat can be recovered by using the exhaust steam for the heating of feed water before it enters the boiler, for the heating of buildings, or in employing the exhaust steam in connection with various manufacturing processes.

6. Mechanical losses due to the friction of the moving parts. These losses may be kept at a minimum by proper lubrication.

Action of the Plain Slide Valve.—Fig. 68 shows a section through a steam engine cylinder with the slide valve in mid-position. *A* and *B* are the steam ports, which lead to the two ends of the cylinder; *C* is the exhaust space. The steam ports are separated from the exhaust space by the two bridges, *D* and *E*. *F* is the steam chest. *V* is a plain slide valve, commonly called a *D* slide valve. The amount *S* that the valve *V* extends over the outside edge of the port, when the valve is at the center of its travel, is called the steam lap. Similarly the amount *X* by which the valve over laps the inside edge of the port when it is in mid-position is called the exhaust lap. *M* and *N* are the steam and exhaust pipes respectively.

A term frequently used in connection with the operation of valves is "lead." By lead is meant the amount that the port is uncovered when the engine is on either dead-center. The object of lead is to supply full pressure steam to the piston as soon as it passes the dead-center.

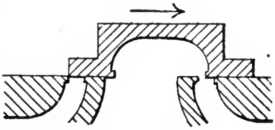


FIG. 69.—Admission.

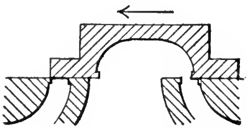


FIG. 70.—Cut-off.

The motion of the valve produces four events: admission, cut-off, release, and compression. Admission is that point at which the valve is just beginning to uncover the port. The position of the valve for this event is shown in Fig. 69. Cut-off occurs, Fig. 70, when the valve covers the port, preventing further admission of steam. This is followed by the expansion of the steam until the cylinder is communicated with the exhaust opening, at which time release, as shown by Fig. 71, occurs. Compression occurs when communication between the cylinder and exhaust opening is interrupted, Fig. 72, and the steam remaining in the cylinder is slightly compressed by the piston. The valve is in the same position at cut-off as it is at admission, only

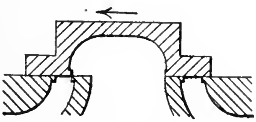


FIG. 71.—Release.

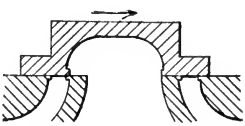


FIG. 72.—Compression.

it is traveling in the opposite direction. Similarly the positions of the valve are the same at release and compression.

Types of Plain Slide Valves.—If the valve is constructed without laps, as shown in Fig. 73, there is no period of valve closure, and the steam acts non-expansively. The release and the cut-off of the steam occur at practically the same instant. The steam admission in one end of the cylinder takes place throughout the entire stroke, while the steam in the opposite end of the cylinder is exhausted at the same time. Such a valve would be uneconomical because of its failure to provide for the expansion of the steam, and as a result is only resorted to in the direct-acting steam pump, which is essentially a special case. For best economy a steam engine should be provided with a valve which cuts off the steam at about one-third of the stroke and releases it somewhere near the end of the stroke.

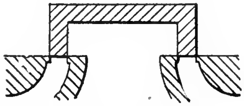


Fig. 73.—Valve without laps.

The simplest type of valve for steam engines is the plain slide valve, illustrated in Fig. 68. This type of valve is not used where steam economy has to be considered. The plain slide valve is used to a limited extent in connection with portable engines, traction engines, or small stationary steam engines. The chief objection to its use on engines of larger sizes is that it is not balanced. If the difference between the steam and the exhaust pressures is large, the force of the steam holding the valve upon its seat is also large, and consequently the force required to move the valve backward and forward may be excessive. This consumes a part of the work developed by the engine, needlessly strains the valve-gear, and makes it difficult to keep the valve steam-tight The objections to the plain slide valve are remedied by the use of balanced valves.

Balanced Valves.—The piston valve, illustrated in Fig. 65, is one form of balanced valve. The pressures upon all sides that would force the valve against its seat are balanced by equal and opposite forces. When well made, and properly fitted with packing rings, little leakage occurs, but small piston valves are often made without packing rings and in such a case leakage is very likely to occur.

The balancing of the flat slide valve is accomplished by the addition of balancing plates. Such a device is shown in Fig. 74. It consists of a machined plate, arranged so that it excludes the high pressure steam from the top of the valve. This eliminates the pressure that would force the valve upon its seat, and the only friction theoretically present is that due to the weight of the valve itself. Various valves employing this principle have been devised. Some are only partially balanced. Others differ in the method of maintaining a steam tight joint between the valve and the balancing plate. The principle involved in all balanced valves is the same.

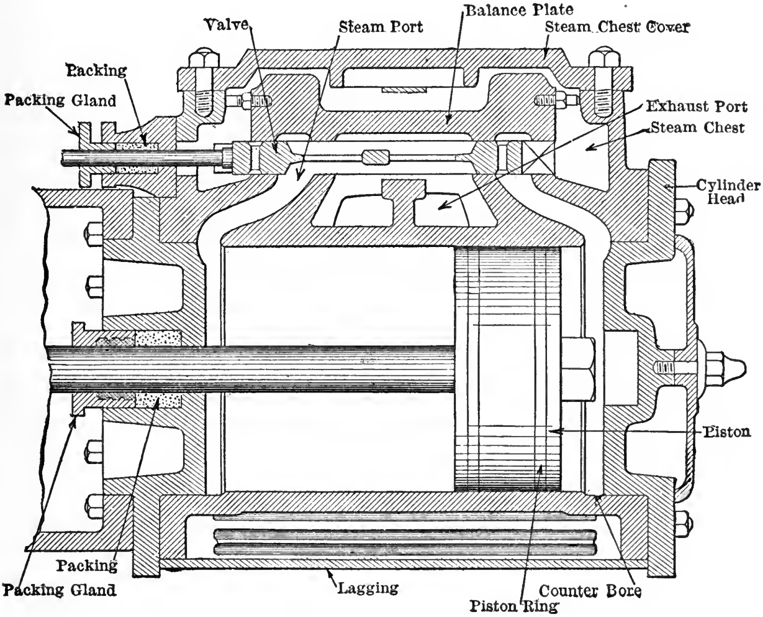


FIG. 74.—Balanced valve.

The Double Ported Valve.—One difficulty in the use of the plain slide valve is that a large movement or travel of the valve is necessary in order to fully open the port. This makes it difficult to use the plain slide valve in engines having a large diameter and short stroke. The double ported valve, Fig. 75, overcomes this difficulty. Instead of using one large port for the passage of the steam, two ports, whose combined areas would equal that of a single port, are used.

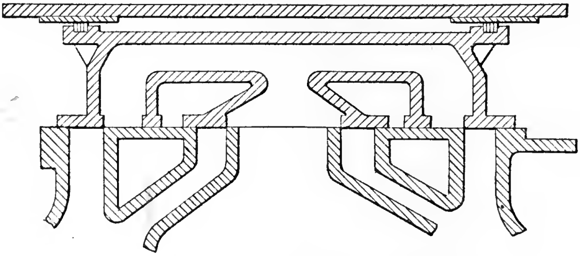


Fig. 75.—Double ported valve.

The Corliss Engine.—The slide valve engine requires long ports or passages for the steam. This increases the amount of surface to which the steam is exposed. Another fault of the slide valve is that the same port is used for the live steam entering the cylinder, after it has been cooled by the exhaust steam. To overcome these objections four-valve engines have been introduced. One of the earliest and best of these types is the Corliss engine.

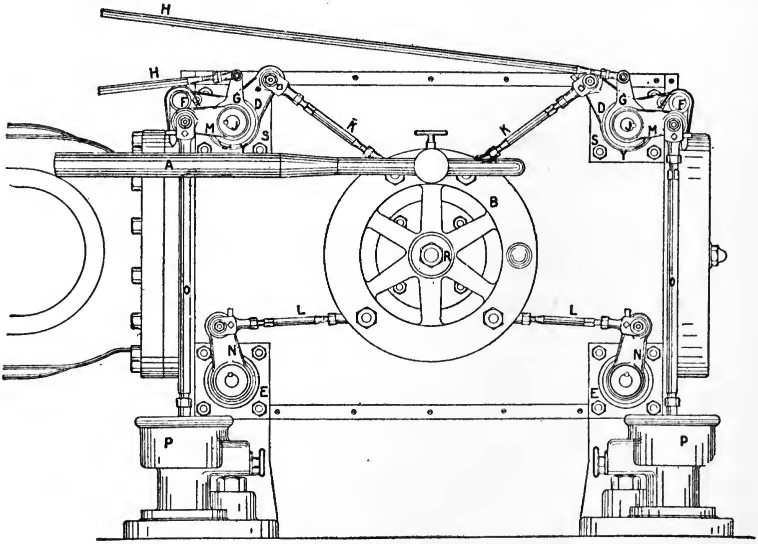


Fig. 76.—Corliss engine cylinder and valve gear.

The cylinder of a Corliss engine is illustrated in Fig. 76. It includes four valves, two for the control of the entering steam and two for the exhaust. The valves are cylindrical in shape and are located at the top and bottom of the cylinder at the extreme ends of the stroke of the engine. The steam and exhaust valves operate respectively in the chambers *S* and *E*. The bell crank levers *D* work loosely on the valve stems; they are connected to the wrist plate *B* by the rods *K*. The steam valve levers *M* are keyed to the valve stem *J*, and are also connected by the rods *O* to the dash pots *P*. The bell crank levers *D* carry at their outer ends V-shaped steam hooks *F*, which are provided with steel catch plates that engage with the arms *M*. The levers *G* are connected by the rods *H* to the governor, and carry upon their outer faces small cams which release the steam hooks. The exhaust valve levers *N* are connected directly through the rods *L* to the wrist plate; their motion being identical with that of a plain slide valve.

In the operation of the engine, the wrist plate is given an oscillating motion by the eccentric to which it is connected through the rod *A*. This causes the bell crank lever *D* to oscillate upward and downward about the spindle *J* as an axis. Upon the extreme downward movement, the steam hook engages the main valve lever *M*, and the upward movement of the hook lifts the lever *M* and opens the valve. The opening of the valve continues until the hook is disengaged by coming in contact with the knock-off cam on lever *D*. The instant the valve is released, the vacuum created in the dash pot *P* causes the quick return of the valve to its normal position. The governor controls the position of the knock-off cam, thus regulating the cut-off by varying the point at which the valve is released.

The trip gear described becomes impractical when the speed of the engine is high. Consequently most Corliss engines, with the trip or releasing valve gears operate at low speeds, usually about 85 to 100 revolutions per minute.

Poppet Valves.—Superheated steam decreases cylinder condensation and increases the economy of the steam engine, but highly superheated steam causes slide valves and those of the Corliss type to warp. To overcome this objectionable feature, and at the same time to take advantage of the gain that may be derived from superheated steam, the poppet valve engine was designed.

Details of one type of poppet valve engine are shown in Fig. 77. The cylinder has four double-seat poppet valves, two are used for regulating the inlet steam and two for regulating the exhaust. The operation of the valves is accomplished by the movement of an eccentric acting through a series of levers. The eccentric is attached to a lay shaft, which runs longitudinally along the outside of the cylinder and is finally geared to the main shaft.

The Uniflow Steam Engine.—The reciprocating steam engines previously described are of the counter-flow or double-flow type. The steam, after its expansion in this type of engine, is reversed in its course, the cylinder walls are subjected to the cooling action of the exhaust steam during the entire exhaust stroke, and the economy of the engine is greatly decreased by the losses due to the condensation and re-evaporation of the steam. The uniflow engine, Fig. 78, has been designed to decrease the above mentioned losses. In the uniflow engine the steam enters at the ends of the cylinder as in the counter-flow engine, but is exhausted through special ports arranged around the center of the cylinder at the farthest point from the heads. The piston acts as an exhaust valve uncovering and covering the exhaust ports. The cylinder heads are exposed to the temperature of the exhaust steam for a very short time. The steam caught in the clearance space is compressed against the cylinder heads, which are jacketed with live steam. The incoming steam is not chilled by coming in contact with cool surfaces, and the losses due to cylinder condensation are greatly decreased.

The single cylinder uniflow engine running condensing is nearly as economical as a compound engine of the counter-flow type. The uniflow engine has also shown remarkable economy at light loads.

Reversing Engines.—Locomotives, marine engines, hoisting, and other reversing engines must be provided with a valve gear by which the direction of rotation may be reversed. The Stephenson link motion and the Walschaert radial valve gear are the two types most commonly used.

The Stephenson link motion is illustrated in Fig. 79. This

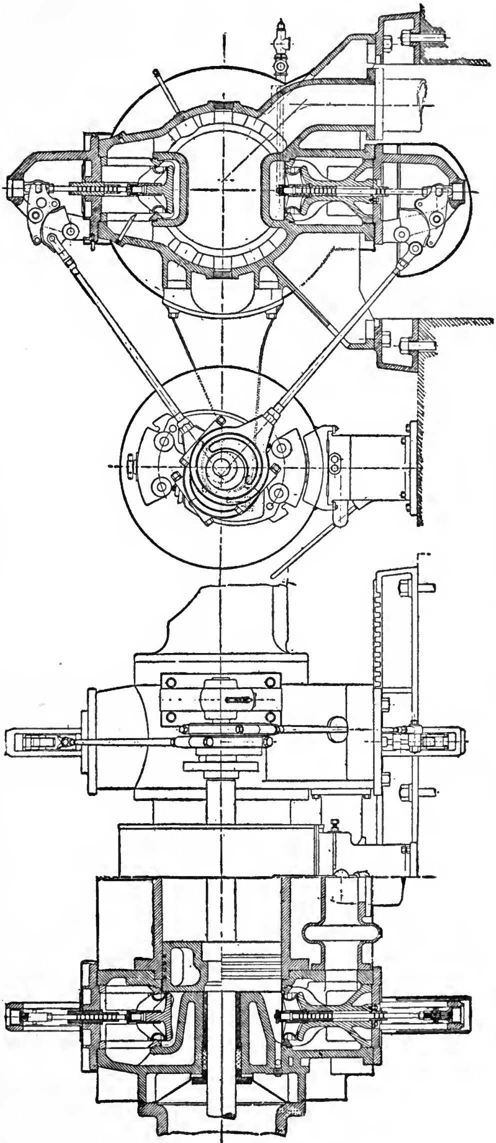


FIG. 77.—Valve gear of poppet-valve engine.

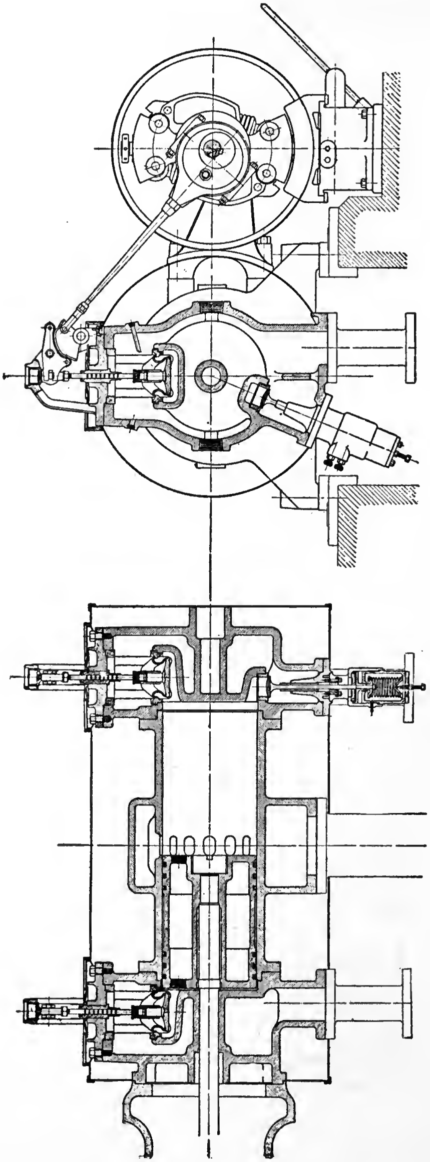


FIG. 78.—Uniflow engine.

motion makes use of two eccentrics *A* and *B*. Eccentric *A* produces rotation of the engine in one direction and is called the forward eccentric; eccentric *B* causes rotation in the opposite direction. Attached to each eccentric is an eccentric rod *R*, which connects to one end of the slotted link *L*. The link *L* is connected to the reversing lever so that its position may be varied at will. The valve stem is attached to the link block in such a manner that the link is free to move. Raising or lowering the link by the reversing lever simply changes the position of the link with reference to the link block and the valve.

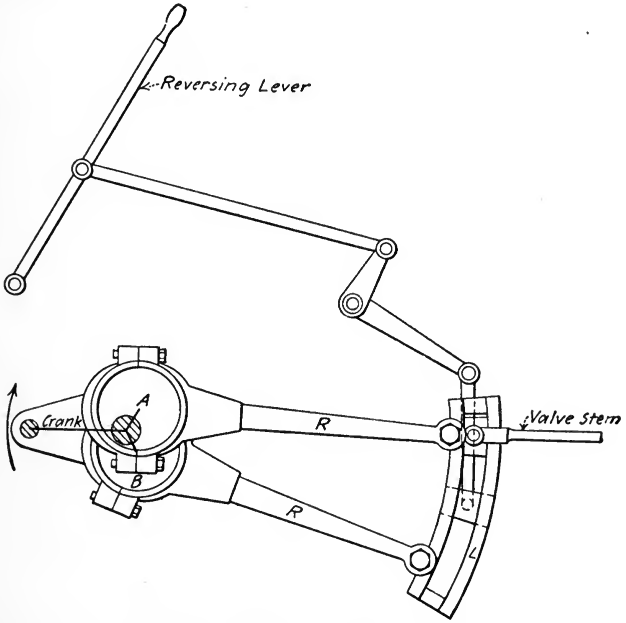


FIG. 79.—Stephenson link motion.

In the position shown, the valve is controlled by the forward eccentric *A*. To reverse the direction of rotation, the link *L* must be raised until the eccentric rod of the backing eccentric *B* is directly in line with the valve stem. The valve motion would then be controlled by the backing eccentric, and the engine shaft would rotate in the opposite direction.

If the link is raised until the valve stem is midway between the two ends of the link, then the valve would be affected equally by both eccentrics. When in this position, very little motion is given to the valve.

The Walschaert valve gear, illustrated in Fig. 80, makes use of a single eccentric placed at an angle of 90° with respect to the crank. A reversing link pivoted at its center is joined to the eccentric by means of the eccentric rod and to the lap and lead lever through the radius rod. The valve is connected directly to the lap and lead lever, which in turn is connected to the cross-head by a small link.

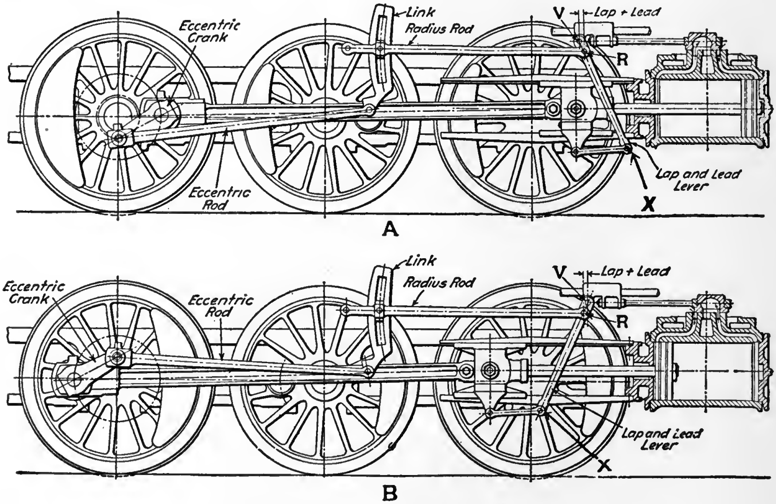


Fig. 80.—Walschaert valve gear.

The motion derived from the cross-head moves the valve an amount equal to the lap plus the lead. The position of the link block with respect to the link is varied by raising or lowering the radius rod. By this means, the motion of the engine can be reversed. When the link block is in the mid-position of the link, the motion derived from the eccentric is neutralized and the valve is moved by the cross-head an amount equal to the lap plus the lead. *A* and *B* show two positions of valve gear.

Condensing and Non-condensing Engines.—Non-condensing engines exhaust directly into the atmosphere, into heating coils, or into feed water heaters, where the heat contained in the exhaust steam is utilized in heating buildings or in raising the temperature of the feed water, as the case may be. Due to the frictional resistance caused by the steam flowing through the exhaust ports, as well as the resistance introduced by the piping and other equipment, the pressure of the exhaust steam in non-condensing engines exceeds atmospheric pressure.

In the operation of a condensing engine, the exhaust steam from the engine cylinder escapes into a condenser, where it is cooled and condensed to water, thus producing a vacuum or a reduction in the back pressure. The reduction in the back pressure increases the work done in the cylinder, if the cut-off remains constant, by increasing the mean effective or unbalanced pressure. If the cut-off is decreased, the same work can be developed by using a smaller quantity of steam.

Generally a condensing engine will use about 25 per cent. less steam than a non-condensing engine of the same size on account of the lower back pressure. Small engines are very seldom operated condensing, as the gain in economy is usually more than balanced by the increased first cost of the equipment and by the greater complications of the power plant. A compound engine when operated condensing will show a greater gain in economy, as compared with non-condensing operation, than will a simple engine. The uniflow engine is very economical when operated condensing. Where the exhaust steam can be used for heating or for manufacturing purposes, the non-condensing installation is more practical.

Multiple-expansion Engines.—The use of multiple-expansion engines is another method for reducing cylinder condensation. In the simple engine, in which the total expansion of the steam is accomplished in one cylinder, the cylinder walls are first exposed to the high temperature of the inlet steam and then are exposed to the low temperature of the exhaust steam. This causes an excessive loss due to the condensation, which can be decreased by dividing the expansion into several pressure stages.

As there is a direct relation between the pressure of steam and its temperature, the decreasing of the pressure range of steam in a cylinder decreases the temperature range and hence decreases the condensation losses also. If steam, instead of being expanded completely in one cylinder, is expanded down to some intermediate pressure in one cylinder and then is exhausted into a second cylinder, where its pressure is reduced to that of the exhaust of a simple engine, the temperature range and condensation losses within each cylinder are decreased. Such an arrangement of cylinders forms a multiple expansion engine. If the pressure range takes place in two stages, the engine is called a compound; if in three stages, triple expansion; and if in four stages, quadruple expansion. Obviously the greater the number of pressure stages, the less will be the temperature range and hence the better the economy. A triple expansion engine is, for that reason, more economical than one operating compound, but the gain in economy when using triple expansion engines is usually more than offset by the increased cost of the equipment, the extra floor space required for the additional cylinder, and the greater complications of the power plant. Triple expansion engines are used in marine practice and in pumping plants, but are seldom found in steam-electric power plants; ordinarily, the compound engine is preferable when conditions warrant a multiple expansion engine.

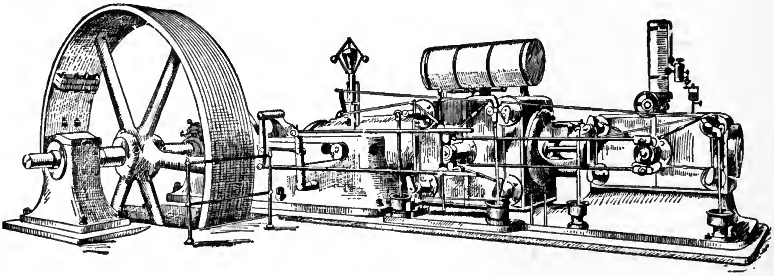


Fig. 81.—Tandem compound engine.

There are two different types of compound engines—the tandem and the cross compound. This classification depends upon the arrangement of the cylinders.

In the tandem compound engine, Fig. 81, the axes of the low and high pressure cylinders are in one straight line. The piston rod is common to both cylinders and the total force transmitted to the single crank is the sum of the forces exerted in each cylinder.

The cross compound engine, Fig. 82, has its cylinders arranged side by side, and the force exerted in each cylinder is transmitted to the separate crank pins, usually set at an angle of 90°. By this arrangement, the turning effort at the crank pin is more nearly uniform.

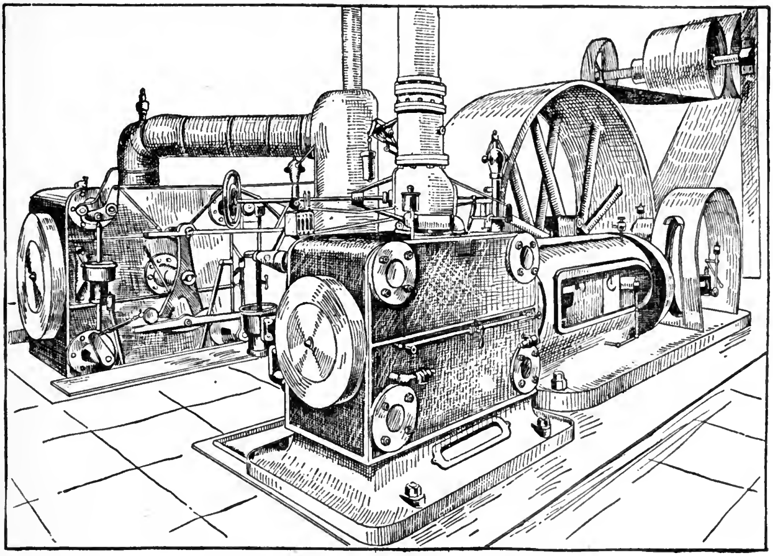


FIG. 82.—Cross compound engine.

The Steam Locomobile.—The steam locomobile is a self-contained power plant, which consists of a compound steam engine mounted upon an internally fired boiler. An insulated sheet-metal smoke box incloses both engine cylinders, a superheater, all steam piping and valves, and a reheater which imparts heat to the steam as it passes from the high pressure to the low pressure cylinder. This arrangement utilizes the heat in the flue gases for superheating the steam before it enters the engine cylinder, for reheating the steam between the high- and the low-pressure cylinder, for reducing heat losses within the engine, and for cutting down the radiation losses of the entire power plant.

The steam from the engine exhausts through a feed-water heater into a condenser, where it is condensed by direct contact with cold water or by contact with tubes through which cold water circulates.

Fig. 83 shows a longitudinal section of a steam locomobile with the various parts named.

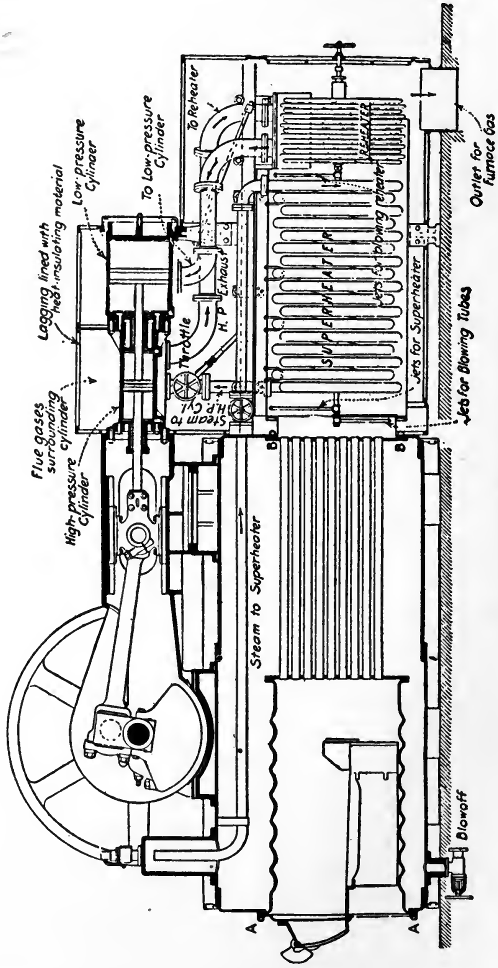


FIG. 83.—The steam locomobile.

Valve Setting.—The object of setting valves on an engine is to equalize the work done in both ends of the piston. The method of procedure will vary with the type of valve, but the general principles will be understood from the following method used in setting the plain slide valve.

Before a valve can be set, the dead centers for both ends of the engine must be accurately determined.

The method of setting an engine on dead center can best be understood by referring to Fig. 84. *H* represents the engine crosshead which moves between the guides marked *G*, *N* is the connecting rod, *R* the crank, *F* the engine flywheel, and *O* is a stationary object.

To set the engine on dead center, turn the engine in the direction in which it is supposed to run, as shown by the arrow, until the cross-head is near the end of its head end travel, and make a small scratch mark on the cross-head and guide as at *A*. At the same time mark the edge of the flywheel and the stationary object opposite each other, as at *B*. Turn the engine past dead center, in the same direction as shown by the arrow, until the mark on the cross-head and that on the guide again coincide at *A*, and mark the flywheel in line with the same point on the stationary object, obtaining the mark *C*. The distance between the two marks on the flywheel is now bisected at *E*. If the mark *E* on the flywheel is now placed in line with the stationary object, the engine will be on the head end dead center. Similarly, the crank end dead center can be found.

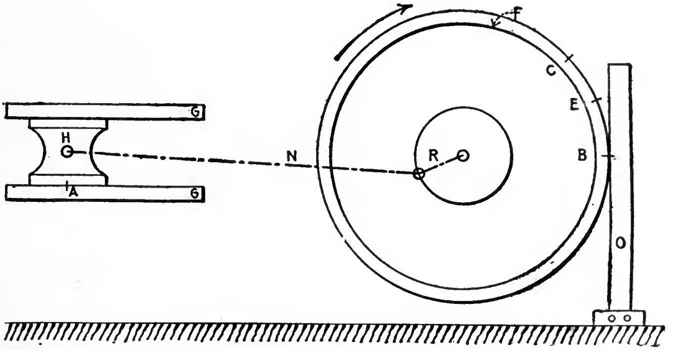


Fig. 84.—Valve setting.

The stationary object may be a wooden board, or a tram may be used with one end resting on the engine bedplate and with the other end used for locating the marks *B*, *C*, and *E* on the flywheel.

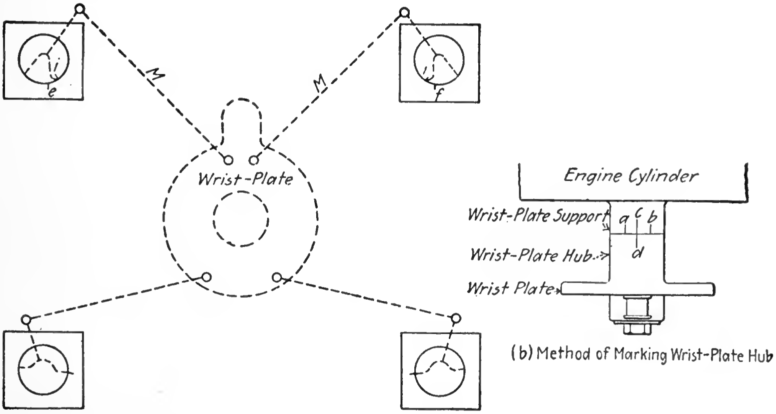
One of two methods may be used in setting the valve. It may be set so that both ends have the same leads, or so that the point of cut-off is the same at both ends.

If the valve is to be set for equal lead on both ends, set the engine on the dead center by the method given above, remove the steam chest cover, and measure the lead at that end. Move the engine to the other dead center and measure the lead again. If the lead on the two ends is not the same, correct the difference, by moving the valve on the valve stem.

To set the engine for equal cut-off, turn the engine until the valve cuts-off at one end and mark the position of the cross-head on the guides. Then turn the engine until the cut-off occurs on the opposite end and again mark this position of the cross-head on the guides. If the cut-off occurs earlier at one end than at the other, change the length of the valve stem until the cut-off is equalized at both ends.

Setting Corliss Valves.—The setting of Corliss valves is more complicated than the setting of plain slide valves, but can be easily accomplished if the customary marks have been placed upon the various parts by the engine builder. The wrist-plate support (Fig. 85*b*) is marked by three lines *a*, *c*, and *b*, while the hub of the wrist-plate itself is provided with one line, *d*. These three lines mark the points of the extreme travel as well as the central position of the wrist-plate when the mark *d* upon the wrist-plate hub coincides with its respective mark, *a* and *b*, or *c* upon the support. When the back bonnets of the valve chambers are removed, there will be found marks, *i* and *j* (Fig. 85*a*), which coincide with the working edges of each of the steam valves. Similar marks, *e* and *f*, on the face of the steam valve chamber coincides with the working edge of each of the steam ports. The exhaust valves and their chambers are marked in a similar manner.

To set the valves, place the wrist-plate in its central position. This point is found when the mark, *d*, upon the wrist-plate hub (Fig. 85*b*) coincides with the central mark, *c*, upon the wrist-plate support. Fasten the wrist-plate in this position by placing a piece of paper between it and the washer which holds the wrist-plate on the stud. Now with the steam valves hooked up, adjust the rod *M* (Fig. 85*a*) leading from the wrist-plate to the double arm lever so that each steam valve will have an equal and slight amount of lap. The amount of this lap varies from 1⁄16″ to 3⁄8″, increasing with the size of the engine. The exhaust valves should be similarly adjusted. After the steam and exhaust valves have been adjusted, the paper between the wrist-plate and the washer should be removed.



(b) Method of Marking Wrist-Plate Hub

(a) Rear of Valves with Bonnets Removed

FIG. 85.—Diagram of Corliss valve mechanism.

The rocker arm, with the eccentric rod attached, should now be placed in a vertical position by means of a plumb line. Loosen the eccentric on the shaft and adjust the eccentric rod so that the extreme travel points of the rocker arm are equidistant from the plumb line. Now connect the hook rod to the wrist-plate and adjust the length of the hook rod so that when the eccentric is revolved on the shaft the mark *d* (Fig. 85*b*) upon the wrist-plate hub coincides with the extreme travel marks *a* and *b* upon the wrist-plate support.

To adjust the lead, place the engine on one of its dead centers and turn the eccentric loosely on the shaft in the direction the engine is to rotate until the steam valve nearest the piston has the proper lead. Now secure the eccentric to the shaft.

To adjust the cut-off, secure the governor in its highest position and disconnect the wrist-plate from the eccentric. Adjust the governor cam rods, so that, as the wrist-plate is oscillated, the releasing of the steam valves in each end of the cylinder occurs when the port is open about ⅛ inch. With the governor in its lowest working position, the releasing gear should not detach the steam valves.

Replace the valve bonnets and see that all connections have been properly made. It is always best to oscillate the wrist-plate a few times to see that the hooks engage properly and that the dash pot rods are adjusted to a proper length.

Horsepower.—The measurement of the power of an engine is in terms of horsepower. If work is done at the rate of 33,000 foot-pounds per minute, one horsepower is said to be developed.

Power takes into consideration the time required to do a certain amount of work and is defined as the rate of doing work. Work means force times distance through which it acts and is independent of time. Thus if steam at a pressure of 100 pounds moves a piston 18 in. in diameter through a distance of 2 ft., the work done is 100 times 508.92 (the area of the piston in inches multiplied by the distance in feet) or 50,892 ft.-lb. The power of the engine, however, depends on the time that the steam requires to move the piston through the given distance and, if the motion is accomplished in 1 second, the power of the engine is five times greater than if 5 seconds were required.

An engine will have a capacity of 1 hp. if it can do 550 ft.-lb. of work in a second, 33,000 ft.-lb. of work in a minute, or 1,980,000 ft.-lb. of work in an hour. To determine the horsepower developed by any motor or engine, it is necessary to find the foot-pounds of work which the motor or engine is doing in a minute and divide this by 33,000. In the example of the previous paragraph, if the piston passes through the distance of 2 ft. in 1/50 min., the power of the engine in horsepower is:

$$\frac{50,892}{33,000 \times \frac{1}{50}} = 77.1.$$

Indicated Horsepower.—The term "indicated horsepower" (I.hp.) is applied to the rate of doing work by steam or gas in the cylinder of an engine, and is obtained by means of a special instrument, called an indicator. The indicator diagrams which result from the use of such an instrument show graphically the action of the steam within the engine cylinder, recording the actual pressure at each interval of the stroke.

One type of indicator is shown in section in Fig. 86. It consists essentially of a cylinder (4), which is placed in direct communication with the engine cylinder. Within the cylinder is the piston (8) to which is attached a spring; as the compression of the spring is proportional to the pressure of the steam, the movement of the indicator piston is directly proportional to the pressure exerted by the steam. The piston is attached to the arm (16). At the end of the arm is a small pencil (23) which records the movement of the piston and graphically indicates the pressure of the steam within the cylinder. Attached to the cylinder (4) is an arm which carries the drum (24). A small paper card to record the motion of the pencil is placed around this drum. The drum is connected to the cross-head of the engine, and is provided with a spiral spring, which returns

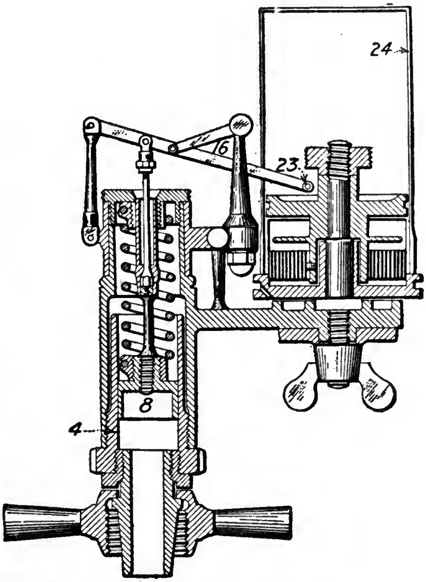


Fig. 86.—Steam engine indicator.

it to its original position after being moved outward by the crosshead.

As the diagram drawn upon the drum of the indicator records the pressure at every instant of the travel of the piston, the average unbalanced pressure, called the mean effective pressure, may be determined and the horsepower calculated.

As an illustration: A steam pump in which a valve without laps is used has the theoretical indicator card illustrated in Fig. 87. The effective pressure is constant throughout the stroke and equals 100 lb. per sq. in. This pressure acts upon a 12-in. (113.1 sq. in. area) piston. Then the total pressure exerted by the steam is:

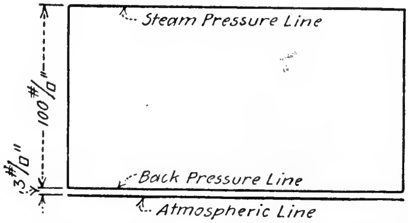


FIG. 87.—Theoretical indicator card from direct-acting steam pump.

Total pressure = 100 × 113.1 = 11,310 pounds.

If the stroke of the piston is 12 inches, the work done in foot-pounds per stroke is:

$$11{,}310 \times \frac{12}{12} = 11{,}310.$$

If this work is exerted upon the piston 50 times per minute, the work the engine will do per minute, if it is single acting, will be:

$$11{,}310 \times 50 = 565{,}500 \text{ ft.-lb.}$$

Since 33,000 ft.-lb. per minute is 1 hp., the power of the engine when single-acting is:

$$\frac{565{,}500}{33{,}000} = 17.1 \text{ I.hp.}$$

As steam engines are usually double-acting, an indicator card would have to be taken of the crank end, as well as of the head end, the unbalanced or the mean effective pressure determined for that end, and the indicated horsepower calculated by the above method, taking into consideration the size of the piston rod. The total indicated horsepower of the engine is the sum of that calculated for the two ends.

Indicator Reducing Motions.—The diameter of the indicator drum is such that the motion of the drum can only be about four inches. In driving the drum from a cross-head, whose motion is in excess of this amount, it is necessary to insert some form of reducing motion. In other words, some arrangement is necessary that will reduce the motion of the cross-head so that it may be reproduced to a smaller scale on the indicator diagram.

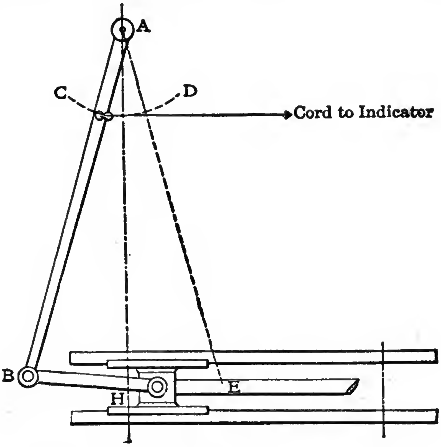


Fig. 88.—Pendulum reducing motion.

Many indicator reducing motions have been devised, but many of these do not produce a true reduction. The test of a true reduction is that, when the cross-head has moved any fraction of its stroke, the indicator drum has been moved the same fraction of its total distance, as measured from one of its extreme positions.

One type of reducing motion is illustrated in Fig. 88, and is often referred to as the pendulum reducing motion. The pendulum arm AB is attached to the frame of the engine at A. Its lower end is attached to the cross-head at H, through the short link. The string to the indicator drum is attached to the arm AB at such a point that the proper reduction in the motion of the cross-head is produced. This form of motion is slightly in error, due to the vertical movement of the point to which the string is attached.

A type of reducing motion, called a reducing wheel, is illustrated in Fig. 89. This type of reducing motion is attached directly to the base of the indicator and thus eliminates any complicated connections to the cross-head that are necessary with other types. The reducing motion consists of two wheels whose diameters may be proportioned to the stroke of the engine and are connected to each other through gears. The cord from the indicator drum is attached to the smaller wheel, while the larger wheel is connected to the cross-head. Changing the diameters of the two wheels permits of indicating engines having strokes between wide limits.

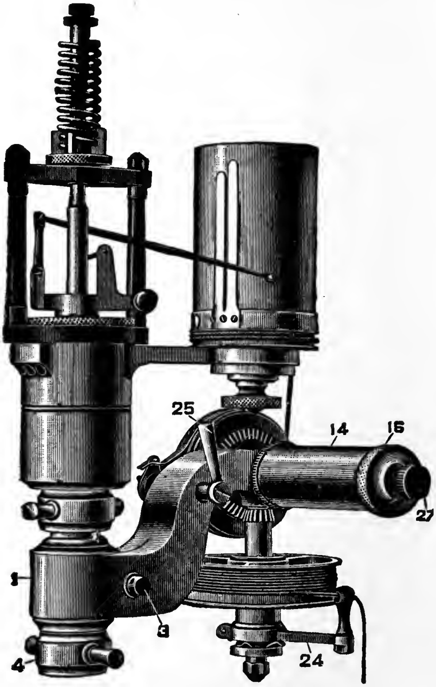


Fig. 89.—Reducing wheel attached to indicator.

The Indicator Card.—A card taken from a steam engine by means of an indicator is shown in Fig. 90. The total length of the card is proportional to the stroke of the engine, and the height at any point is proportional to the pressure of the steam in the cylinder. The events of the stroke in the card are marked: admission A, cut-off C, release R, compression K. The pressure may be measured at any point on this card if the scale of the spring is known. Springs are provided so that various pressures are required to compress the spring sufficiently to cause the pencil to be moved 1 inch. A 60-pound spring, for instance, will require a pressure of 60 pounds per sq. in. to cause the pencil point to move 1 inch. Or conversely, if the height of an indicator card is 1½ inches at some point in the diagram and a 60-pound spring is used in making the card, the pressure exerted by the steam in the cylinder is:

$$60 \times 1\tfrac{1}{2} = 90 \text{ pounds per sq. in.}$$

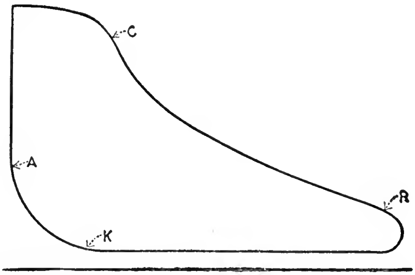


Fig. 90.—Steam engine indicator card.

The Measurement of Power from Indicator Cards.—A close analysis of an indicator card will show that certain pressures are exerted in the cylinder during the forward stroke and that lesser pressures exist in the cylinder during the return stroke. The two series of pressures differ in that those exerted during the forward stroke act upon the piston of the engine and are transmitted to the main shaft or flywheel, while on the return stroke the engine itself, due to the momentum which has been stored in the various parts during the forward stroke, must force the steam out of the cylinder and compress it. Thus the total forward pressure exerted in the cylinder is not effective in producing power, but some must be utilized to exhaust the steam and to produce the compression. The effective pressure is the difference between the total pressure and the back pressure. This difference is graphically represented by the pressure within the indicator diagram. To use this value in determining the foot-pounds of work, it must be reduced to the mean effective pressure exerted throughout the stroke. The mean effective pressure (M.E.P.) can best be found by the use of a planimeter, Fig. 91, which is an instrument for measuring areas. Thus

$$\text{M.E.P.} = \frac{\text{area of card}}{\text{length of card}} \times \text{scale of spring.}$$

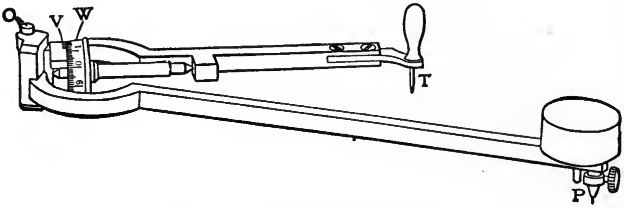


FIG. 91.—Polar planimeter.

Another means often employed in the absence of a planimeter is to divide the length of the card into 10 equal parts, as shown in Fig. 92, and obtain the average of the heights in inches of the 10 trapezoids formed. Thus from Fig. 92

$$\text{M.E.P.} = \frac{a + b + a + d + e + f + g + h + i + j}{10} \times \text{scale of spring.}$$

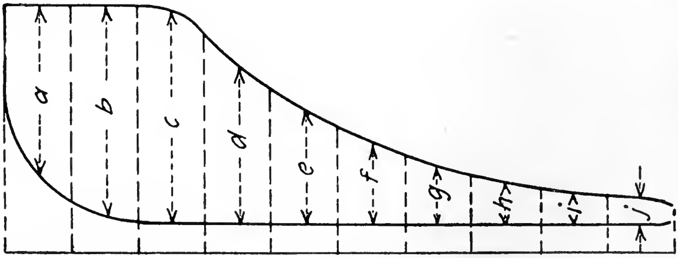


FIG. 92.—Ordinate method of measuring mean effective pressure.

The indicated horsepower developed by one end of the cylinder is:

$$\frac{plan}{33{,}000}$$

Where p = mean effective pressure in pounds per sq. in.
l = length of stroke in feet
a = area of piston in square inches
n = number of revolutions per minute

In the crank end of the cylinder this same formula will apply with the exception that the effective area of the piston is reduced by the area of the piston rod.

As an illustration, the following data was obtained from the test of a steam engine:

Diameter of engine cylinder 10 inches (area 78.54 sq. in.).
Diameter of piston rod 1¾ inches (area 2.405 sq. in.)
Stroke of engine 12 inches
Speed of engine 280 r.p.m.

If the mean effective pressure in the head end side of the cylinder is found to be 41.64.

The I.hp. in the head end side is then:

$$\frac{41.64 \times \frac{12}{12} \times 78.54 \times 280}{33{,}000} = 27.73 \text{ hp.}$$

The indicated horsepower in the crank end side of the cylinder is obtained in the same manner, but the effective area in this side of the cylinder, which is found by deducting the area of the piston rod, must be used.

If the mean effective pressure in the crank end is 35.76, the I.hp. in the crank end is then:

$$\frac{35.76 \times \frac{12}{12} \times (78.54 - 2.405) \times 280}{33{,}000} = 23.10 \text{ hp.}$$

The total indicated horsepower developed by the engine is:

$$27.73 + 23.10 = 50.83 \text{ hp.}$$

Valve Setting by Indicator Cards.—In general, one of the best methods of setting the valve of a steam engine is by means of the steam engine indicator. Any distortion in the events of the stroke is easily detected, and a little study of such diagrams suggests the proper steps to correct the difficulty.

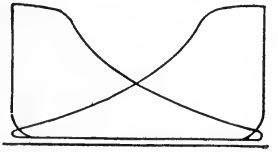


Fig. 93.—Indicator cards, valves properly set.

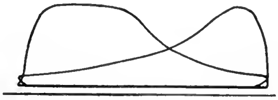


Fig. 94.—Indicator cards, valves improperly set.

Fig. 93 shows indicator cards taken from the two ends of a cylinder when the valve is properly set. The four events in each cylinder occur at very nearly the same point in each stroke, and the cards compare favorably with that of an ideal diagram.

Fig. 94 shows indicator cards taken from two ends of a cylinder when the valve is poorly set. Comparing the cards from the two ends of the cylinder, the same events in the two ends occur at different points in the stroke; this indicates that an adjustment of the valve is necessary.

Fig. 95 shows samples of good and imperfect indicator diagrams. The cause of each defect is explained.

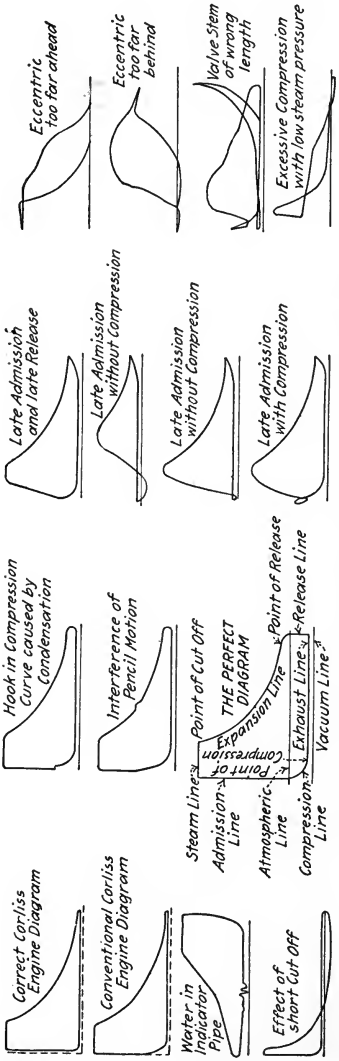


Fig. 95.—Samples of ideal and imperfect indicator diagrams.

Brake Horsepower.—Brake horsepower represents the actual effective power which a motor or engine can deliver for the purpose of work at a shaft or a brake. An instrument for the measurement of the brake horsepower of motors, called a Prony brake, is shown in Fig. 96. This brake consists of two wooden blocks *BB* which fit around the pulley *P*, and are tightened by means of the thumb nuts *NN*. A projection of one of the blocks, the lever *L*, rests on the platform scale *S*. When the brake is balanced, the power absorbed is measured by the weight, as registered on the scales, multiplied by the distance through which it would pass in a given time if free to move. If l is the length of the brake arm in feet, measured from the center of the shaft to the point of support on the scales, w the net weight as registered on the scales in pounds, and n the revolutions per minute of the motor, the horsepower absorbed can be calculated by the formula:

$$\text{Brake horsepower} = \frac{2\pi l w n}{33{,}000}$$

As an illustration, the net scale reading of an engine running at 250 r.p.m. is 80 lb. If the length of the brake arm is 5¼ feet, calculate the brake horsepower developed.

$$\text{Brake horsepower} = \frac{2 \times 3.1416 \times 5.25 \times 80 \times 250}{33{,}000} = 20.00$$

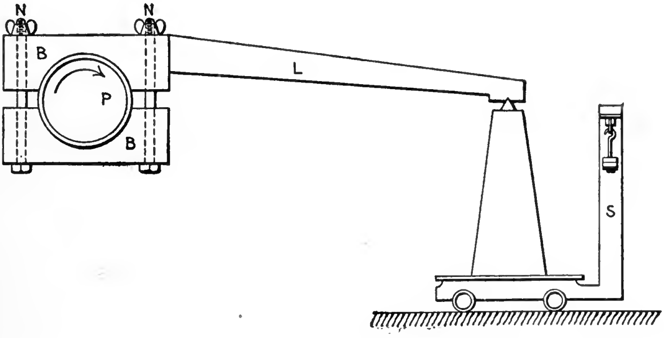


Fig. 96.—Prony brake.

Friction Horsepower.—The indicated horsepower of an engine would be equal to that of the brake horsepower if no losses occurred in the machine. The indicated horsepower is, however, always in excess of the brake horsepower by an amount equivalent to the power consumed in friction. The difference between the indicated horsepower and the brake horsepower is consequently the friction horsepower.

$$\text{F.hp.} = \text{I.hp.} - \text{B.hp.}$$

Mechanical Efficiency.—The mechanical efficiency of an engine is the ratio of the brake horsepower (B.hp.) to the indicated horsepower (I.hp.).

$$\text{Mech. efficiency} = \frac{\text{B.hp.}}{\text{I.hp.}}$$

The mechanical efficiency is the percentage of the indicated horsepower that is delivered to the shaft as effective work. One hundred minus the per cent. mechanical efficiency gives the percentage of the indicated horsepower that is lost in friction.

Steam-engine Governors.—The function of a governor is to control the speed of rotation of a motor irrespective of the power which it develops. In the steam engine the governor maintains a uniform speed of rotation either by varying the initial pressure of the steam supplied, or by changing the point of cut-off and hence the portion of the stroke during which steam is admitted.

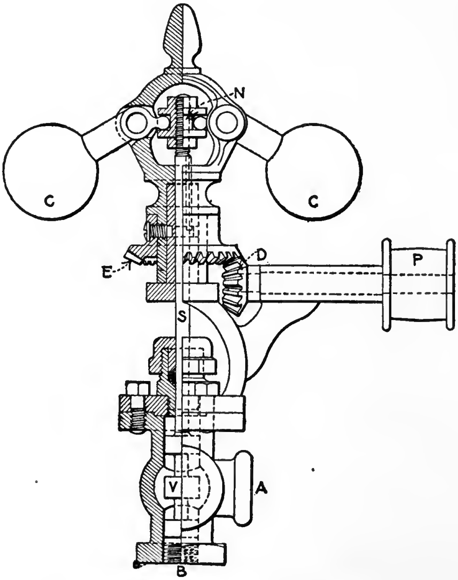


Fig. 97.—Steam engine governor.

Governors which regulate the speed of an engine by varying the initial pressure of the steam supplied to the engine are called throttling governors. The throttling governor is the simplest form of governor, and is used mainly on engines of the plain slide-valve type. In Fig. 97 is given a section of a throttling governor, showing details. This form of governor is attached to the steam pipe at *A*, and is connected to the engine cylinder at *B*, so that the steam must pass the valve *V* before entering the engine. The valve *V* is a balanced valve and is attached to a valve stem *S*, at the upper end of which are two balls *CC*. The valve stem and balls are driven from the engine shaft by a belt, which is connected to the pulley *P*, and which in turn runs the bevel gears *D* and *E*. As the speed of the engine is increased the centrifugal force makes the balls fly out, and in doing so they force down the valve stem *S*, thus reducing the area of the opening through the valve, and the steam to the engine is throttled. As soon as the engine begins to slow down, the balls drop, increasing the steam opening through the valve *V*. The speed at which the steam is throttled can be changed within certain limits by regulating the position of the balls by means of the nut *N*.

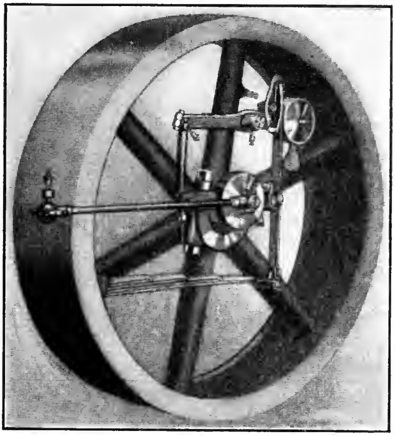


FIG. 98.—Shaft governor.

Most of the better engines are governed by varying the point of cut-off and hence the total volume of steam supplied to the cylinder. In high-speed automatic engines this is accomplished by some form of flywheel or shaft governor, which controls the point of cut-off by changing the position of the eccentric.

One form of flywheel governor is shown in Fig. 98. The sheave of the eccentric is mounted upon an arm which is pivoted to the flywheel. The eccentric sheave contains a slot which passes over the shaft, and the outer end of the arm is attached to the weight as shown. In the operation of the governor, centrifugal force causes a movement of the governor weight, and in so doing the position of the eccentric and hence the cut-off is changed. As the speed of the engine increases, the cut-off is reduced; and when the speed slows down the cut-off is increased.

Engine Details.—The general construction of steam-engine cylinders can be seen from the previous illustrations. Steam-engine cylinders are made of cast iron. As the cylinder wears, it has to be rebored so as to maintain true inside surfaces. The thickness of the cylinder walls should be not only sufficient to withstand safely the maximum steam pressure, but should allow for reboring. All steam-engine cylinders should be provided with drip cocks at each end in order to drain the cylinder and steam chest when starting.

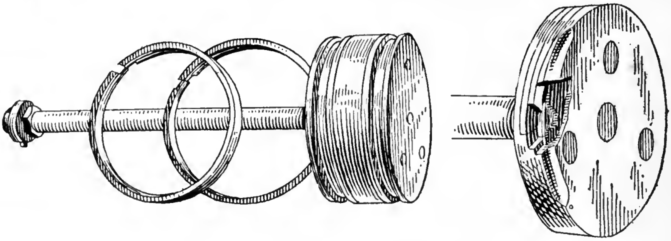


Fig. 99.—Steam engine piston.

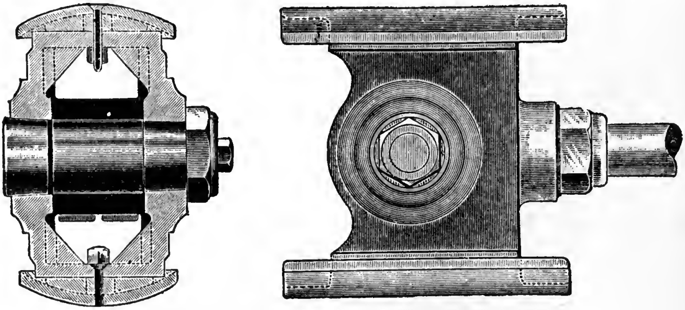


Fig. 100.—Steam engine cross-head.

A good piston should be steam tight and at the same time should not produce too much friction when sliding inside the engine cylinder. The piston is usually constructed somewhat smaller than the inside diameter of the engine cylinder, and is made tight by the use of split cast-iron packing rings. In Fig. 99 is illustrated a piston with its packing rings.

The general construction of steam-engine cross-heads is illustrated in Fig. 100. All cross-heads should be provided with shoes which can be adjusted for wear.

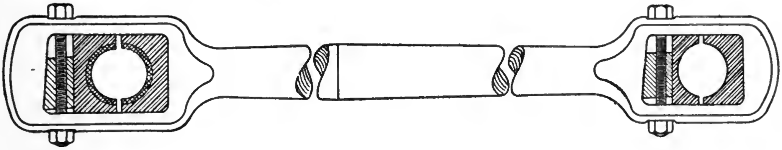


Fig. 101.—Steam engine connecting rod.

Fig. 101 shows a connecting rod. A connecting rod should be so constructed that the wear on its bearings can be taken up. This is usually accomplished by wedges and set-screws as illustrated.

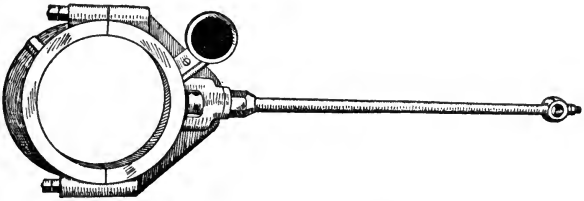


Fig. 102 —Eccentric rod and strap.

Some engines have their cranks located between the two bearings of an engine, and are called center-crank engines. Engines which have their cranks located at the end of the shaft and on one side of the two bearings are called side-crank engines.

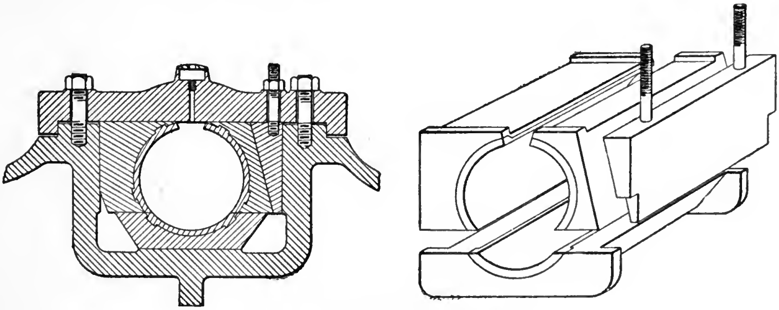


Fig. 103.—Main bearings.

The eccentric is a special form of crank. It is usually set somewhat more than 90° ahead of the crank and gives motion to the valve or valves in the steam chest of the engine. Fig. 102 shows an eccentric rod and strap.

The main bearings of steam engines are illustrated in Fig. 103. These bearings are usually made in three or four parts and can be adjusted for wear by means of wedges and setscrews fastened with locknuts.

Lubricators.—The function of lubrication is to decrease the frictional losses which occur in steam engine operation. All rubbing surfaces at which friction is produced must be lubricated.

Bearings may be lubricated by grease cups as illustrated in Figs. 104 and 105. The first type is used on stationary bearings, the grease being forced out by screwing the cap down by hand. The type illustrated in Fig. 105 is automatically operated, and is used for the lubrication of crankpins.

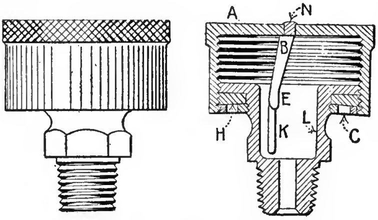


Fig. 104.— Grease cups.

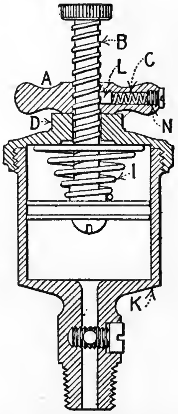
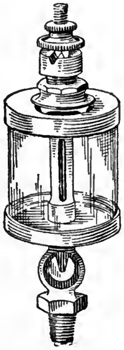


Fig. 105.—Automatic grease cup.

If oil is used, a sight-feed lubricator is employed, as shown in Fig. 106. By means of the sight-feed types the flow of oil can be regulated and the drops of oil issuing from the lubricator can be seen.

For the lubrication of steam-engine cylinders some form of sight-feed automatic steam lubricator, as illustrated in Fig. 107, should be employed. This form of lubricator is used to introduce a heavy oil into the steam entering the cylinder. This oil is a specially refined heavy petroleum oil which will neither decompose, vaporize, nor burn when exposed to the high temperature of steam. Steam from the pipe *B* leading to the engine cylinder is admitted through the pipe *F* to the condensing chamber *L*, where it is condensed and flows through the pipe *P* to the bottom of the chamber *A*. The oil which is contained in chamber *A* rises to the top, is forced through the tube *S*, ascends in drops through the water in the gage glass *H*, and into the steam pipe *K* leading to the steam chest. The amount of oil fed is regulated by the needle valve *E*. The gage glass *J* shows the amount of oil in the chamber *A*. In order to fill the chamber *A*, the valves on the pipes *F* and *H* are closed, the water is drained out through *G*, and the cap *D* is removed for receiving the oil.



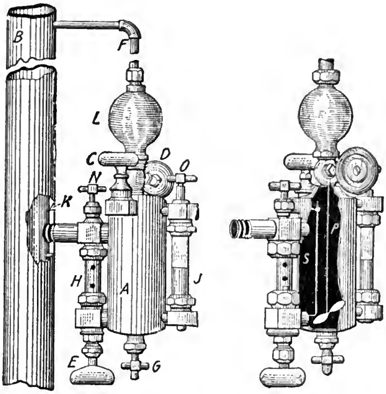


Fig. 106.—Sight-feed lubricator. Fig. 107.—Sight-feed automatic lubricator.

Steam Engine Economy.—The economy of steam engines is usually expressed in pounds of steam consumed per horsepower per hour. In the case of steam-electric power plants the economy is expressed in pounds of steam consumed per kilowatt-hour. The steam consumption of simple, non-condensing engines will vary, under good operating conditions and at full load, from 20 to 35 pounds per horsepower per hour, depending upon the type of valve gear used. Compound condensing engines consume 12 to 20 pounds of steam per horsepower per hour.

Reciprocating steam engines are usually operated at steam pressures varying from 75 to 200 pounds per square inch. The gain produced in economy by increasing the steam pressure from 80 to 100 pounds per square inch is about twice as great as that resulting from increasing the steam pressure from 180 to 200 pounds per square inch. In general, the practical limit for steam pressure is mainly one of expense. The first cost and the cost of upkeep of steam power plant equipment increases with the steam pressure.

The exhaust pressure at which an engine is operated depends upon the use to which the exhaust steam can be put. If the exhaust steam can be used for heating or for manufacturing purposes engines are operated non-condensing. With large compound engines the gain due to condensing is considerable. Condensing reciprocating engines give best economy with back pressures of about two pounds absolute (26 inches vacuum).

The quality of the steam influences the losses due to condensation and re-evaporation. The use of superheated steam, considering the cost of producing the superheat, will increase the net economy of steam engines by about 5 per cent. for every 100 degrees superheat.

Installation and Care of Steam Engines.—Foundations for stationary steam engines are usually put in by the purchaser, the manufacturer furnishing complete drawings for that purpose. Drawings of a board template are also included. A template is a wooden frame which is used in locating the foundation bolts and for holding them in position while building the foundation.

Before starting on the foundation a bed should be prepared for receiving it. The depth of bed depends on the soil. If the soil is rocky and firm, the foundation can be built without much difficulty. When the soil is very soft, piles may have to be driven.

The wooden template is then constructed from the drawings, holes being bored for the insertion of foundation bolts.

Foundations are usually built of concrete. The concrete mixture should consist of 1 part of cement, 2 parts of sharp sand, and 4 parts of crushed stone. The stone should be of a size as will pass through a 2-inch ring. In starting on a concrete foundation, a wooden frame of the exact shape of the foundation is built. The template is then placed in position in the manner shown by Fig. 108, and the bolts are put in, the heads of the bolts being at the bottom in recesses of cast iron anchor plates marked *P*. Often the foundation bolts are threaded at both ends and the anchor plates are held in place by square nuts. A piece of pipe should be placed around each bolt, so as to allow the bolts to be moved slightly to pass through the holes in the engine bedplate, in case an error should occur in the placing of the bolts, or in the location of the bolt holes in the engine bedplate.

With the frame, template, and foundation bolts in place, the concrete can now be poured and tamped down. After the concrete has set, the template is removed and the foundation is made perfectly level. It is well to allow a concrete foundation to set several weeks before placing the full weight of the engine on it.

When the foundation is ready, the engine is placed in position and leveled by means of wedges The nuts on the bolts are now screwed down and the engine is grouted in place by means of neat cement, this serving to fill any crevices and to give the engine a perfect bearing on the foundation.

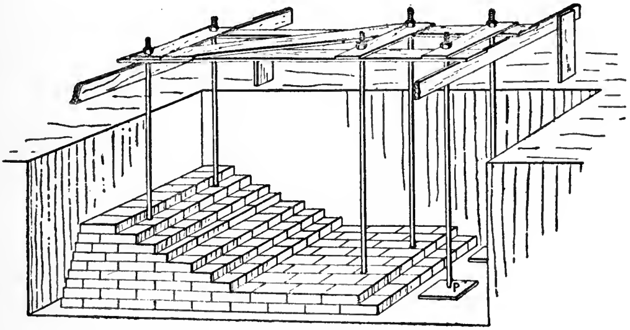


Fig. 108.—Foundation in the process of construction.

After erecting the engine and all its auxiliaries, including pipes, valves, cocks, and lubricators, all the parts should be carefully examined and cleaned, and a coating of oil should be applied to all rubbing surfaces, cylinder oil being used for the wearing parts in the valve chest and cylinder.

Before the engine is operated for the first time, it is well to adjust bearings, and turn the engine over slowly until an opportunity has been given for any inequalities due to tool and file marks to be partially eliminated, and also to prevent heating that might occur if there was an error in adjustment.

When the engine is ready to start, the steam throttle valve should be slowly opened to allow the piping to warm up, but leaving the drain cock in the steam pipe, above the steam chest, open to permit the escape of condensation. While the piping is being warmed up all the grease cups and lubricators are filled. Before opening the throttle valve, all cylinder and steam-chest drain cocks should be opened to expel water, and the flow of oil started through the various lubricators. The throttle valve is then opened gradually, and both ends of the engine warmed up. This can be accomplished in the case of a single-valve engine by turning the engine over slowly by hand to admit steam in turn to each end of the cylinder. In starting a Corliss engine the eccentric is disconnected from the wrist-plate and the wrist-plate is rocked by hand sufficiently to allow steam to pass through each set of valves. The drain cocks are closed soon after the throttle is wide open and the engine is gradually brought up to speed.

When stopping an engine, close the throttle valve. As soon as the engine stops, close the lubricators, wipe clean the various parts, examine all bearings, and leave the engine in perfect condition ready to start.

The above instructions apply to non-condensing engines. If the engine is to be operated condensing, the circulating and air pumps should be started while the engine is warming up. The other directions apply with slight modifications to all types of steam engines.

In regard to daily operation, cleanliness is of great importance. No part of the engine should be allowed to become dirty and all parts must be kept free from rust. It is well to draw off all the oil from bearings quite frequently and to clean them with kerosene before refilling with fresh oil. In starting it is well to give the various parts plenty of oil, but the amount should be decreased as the engine warms up. An excess of oil should be avoided.

Competent engine operators usually make a practice of going over and cleaning every bearing, nut, and bolt, immediately on shutting down. This practice not only keeps the engine in first-class condition, as regards cleanliness, but enables the operator to detect the first indication of any defect that, if overlooked, might result seriously.

If a knock develops in a steam engine, it should be located and remedied at once. Knocking is usually due to lost motion in bearings, worn journals, or cross-head shoes, water in the cylinder, loose piston, or to poor valve setting. Locating knocks in steam engines is to a great extent a matter of experience and no definite rules can be laid down which will meet all cases.

However, one may, by careful attention to the machine, learn to trace out the location of a knock in a comparatively short time. He must bear in mind that he cannot rely on his ear for locating it, as the sound produced by a knock is, in many cases, transmitted along the moving parts, and apparently comes from an entirely different point.

A knock, due to water in the cylinder, is usually sharp and crackling in its nature, while that in the case of a crank or a cross-head pin is more in the nature of a thud. If the knock should be due to looseness of the main bearings, the location may be detected by carefully watching the flywheel. If the cross-head is loose in the guides the observer may be able to detect a motion crossways of the cross-head, but it is not likely that he can do this with accuracy in the case of a high-speed engine; in such cases the cross-head should be tested when the engine is at rest. No adjustment should be made in bearings or moving parts of an engine unless the machine is at a standstill or is being turned by hand; never when under its own power.

The heating of a bearing is always due to one of five causes:

1. Insufficient lubrication due to insufficient quantity of oil, wrong kind of oil, or lack of proper means to distribute the oil about the bearings.
2. The presence of dirt in the bearings.
3. Bearings out of alignment.
4. Bearings improperly adjusted. (They may be either too tight or too loose.)
5. Operation in a place where the temperature is excessive.

In case a bearing should run hot and it is very undesirable to shut down, it is generally possible to keep going by a liberal application of cold water upon the entire heated surface or surfaces. It is sometimes possible to stop heating by changing from machine oil to cylinder oil which has a higher flash point.

Should a bearing, particularly a large one, be over-heated to the extent that it is necessary to shut down the engine, do not shut down suddenly or allow the bearing to stand any length of time without attention. This is particularly important in the case of babbitted bearings, as the softer metal of the bearings will tend to become brazed to, or fused with, the harder metal of the shaft, and it may be necessary to put the engine through the shop before it can be used again.

In case of the necessity of shutting down for a hot bearing, first remove the load, then permit the engine to revolve slowly under its own steam until the bearing is sufficiently cool to permit the bare hand to rest upon it.

The presence of water in the cylinder is always a source of danger, and care should be taken that the water of condensation is thoroughly drained from the cylinder when the engine is first started, at shutting down, and at regular intervals throughout the operation. An accumulation of water may readily cause the blowing out of a cylinder head with its resultant loss to property and possibly to life. There are several appliances now on the market which automatically safeguard the cylinder head by providing a weak point in the drain system which will relieve the excess pressure before the cylinder head gives way.

Problems

1. Examine the power plants in your vicinity and report upon the types of valve gears used. If the valve mechanisms in any case differ from those in this text book, hand in clear sketches of such valve gears.

2. Examine the locomotives entering your city and report upon the reversing mechanisms used.

3. Check and correct the valve setting of some engine, accessible to you, and report upon the method used.

4. Explain, using clear sketches, how a Corliss engine is governed.

5. Calculate the indicated horsepower of an 18″ × 24″ steam engine operating at a speed of 110 revolutions per minute, if the head-end mean effective pressure is 30 pounds per square inch, the crank-end mean effective pressure 30.5 pounds, size of piston rod is 2 inches.

6. An engine operating at a speed of 200 revolutions per minute is tested by means of a Prony brake. If the length of the brake arm is 42 inches and the net weight as registered on platform scales 35 pounds, calculate the brake horsepower of the engine.

7. Prepare a table showing economies which can be expected at full load, half load, and quarter load, from the following types of engines:

(*a*) Simple high-speed automatic engines, sizes 50 to 150 horsepower.
(*b*) Corliss engines, simple and compound non-condensing.
(*c*) Compound condensing engines in large units.
(*d*) Uniflow engines, condensing and non-condensing.

CHAPTER VIII

STEAM TURBINES

The steam turbine differs from the reciprocating steam engine, in that it produces rotary motion directly and without any reciprocating parts. The simple steam turbine is a wheel which is given rotary motion by a steam jet impinging on its blades. The elastic force of the steam in the turbine does not act upon the surface of a moving piston, but upon the mass of the steam itself, converting nearly all of the available energy in the steam between certain pressure limits, into velocity.

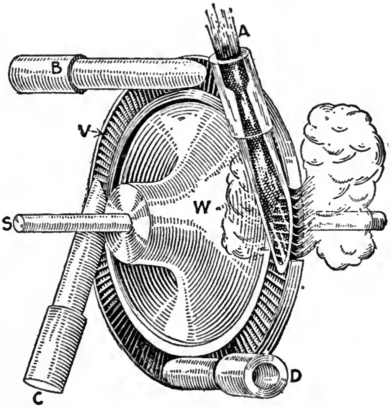


Fig. 109.—De Laval steam turbine.

In one type of steam turbine, (Fig. 109), the jet of steam from a fixed expanding nozzle is directed upon moving curved blades. All the expansion occurs in a nozzle, resulting in a steam jet of high velocity which does work. This is called the impulse type of steam turbine. *A*, *B*, *C*, and *D* are stationary expanding nozzles in which the steam is completely expanded and the steam jet of high velocity strikes the blades *V*, giving a direct rotary motion to the wheel *W* and also to the shaft *S*.

In another type, called the reaction turbine, (Fig. 129), the steam is expanded within the stationary and the moving blades of the machine, and work is partly produced by the reaction of the expanding steam as it flows from the moving blades to the stationary or guide blades. No commercial steam turbines operate upon the pure reaction principle, but work by both the impulse of the steam against the blades and by the reaction of the steam as it leaves the blades.

Advantages of the Steam Turbine.—As compared with the reciprocating engine the steam turbine has the following advantages:

1. The speed of the steam turbine is practically uniform. This makes the steam turbine a very desirable motor for electric central stations.

2. The steam turbine requires no internal lubrication, and the exhaust steam may be used again without oil filtration.

3. The steam turbine can operate at lower back pressures, that is at higher vacua, than reciprocating engines. It is not practical to operate steam engines at vacua greater than 26 inches. Steam turbines are commonly operated at a vacuum of 28 inches and some turbine installations maintain a vacuum greater than 29 inches. Increasing the vacuum from 26 to 29 inches increases the energy of the steam very nearly the same amount as does the increase in steam pressure from 75 to 150 pounds.

4. The steam turbine is better adapted to use highly superheated steam than are reciprocating engines equipped with slide valves or with Corliss valves. With reciprocating steam engines, other than those equipped with poppet valves, steam temperature above 450°F., are seldom exceeded. Above such temperature lubrication is unsatisfactory, and distortion of parts may take place. Temperatures of 600°F. and higher are common in steam turbine practice.

5. The steam turbine occupies less space than the reciprocating engine and weighs less per unit capacity.

6. The steam turbine can be built in very large sizes. Reciprocating engines of capacities as great as 10,000 horsepower are very rare. Steam turbines, each of which has a capacity of 30,000 kilowatt (over 40,000 horsepower) and greater, are found in large

generating stations. In 1918, a 70,000 kilowatt steam turbine was installed. Other steam turbines varying in capacity from 10,000 to 60,000 kilowatts have been in service in some of the large central stations from one to five years, operating successfully from 16 to 20 hours per day.

7. Steam turbines in large sizes are cheaper than reciprocating engines.

8. Where turbines of large capacities can be utilized, electric current can be generated cheaper than with reciprocating engines.

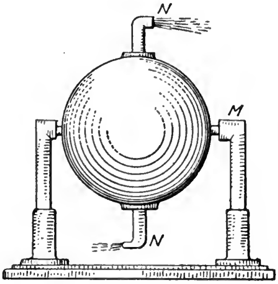


Fig. 110.—Hero's Turbine.

History of the Steam Turbine.—The history of the steam turbine dates back to the second century before the birth of Christ, when Hero of Alexandria contrived a steam motor which is illustrated in Fig. 110. The Hero's turbine consisted of a hollow spherical vessel rotating on two supports. The steam was delivered to the vessel through one of the supports M, and escaped from it through two bent pipes or nozzles N, N pointed in opposite directions. Rotation of the sphere was produced by the

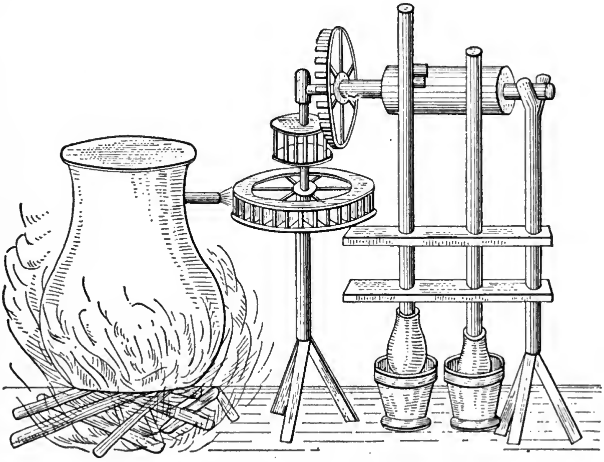


Fig. 111.—Branca Turbine.

reaction due to the steam escaping from the nozzles. The modern reaction turbine is a modification of the Hero motor.

The Branca Wheel, Fig. 111, which was designed in 1629, resembled a water wheel, and was driven by a jet of steam directed by means of a nozzle upon buckets attached to the wheel.

The steam turbine did not become a commercial success until near the end of the nineteenth century. The delay in the practical utilization of the turbine was due to the following causes:

1. There was very little demand for a high speed motor of large capacity until the development of the electric central station.

2. Lack of scientific knowledge concerning the laws governing the flow of steam has prevented the perfection of a machine which could operate at practical speeds. All the earlier turbines were single stage machines and operated at very high speeds. The method of reducing the speed of the turbine shaft, by passing the steam through a number of wheels in series, was not discovered until about the middle of the nineteenth century.

3. The simple one wheel turbines, of which the Branca turbine was the prototype, could not be built as commercial motors until the developments in the science of metallurgy made possible the manufacture of materials which were capable of bearing without rupture the high rotative speeds.

The De Laval Simple Impulse Steam Turbine.—The De Laval steam turbine (Fig. 109) was the first successful simple impulse turbine. The inventor of this turbine, Dr. Gustaf de Laval, designed the expanding nozzle in 1889. He also patented the principle of flexible supports for turbines or other bodies intended to rotate at high velocities.

Fig. 112 illustrates a sectional plan of a De Laval turbine. Steam enters the steam chest, where it is distributed to one or more nozzles, depending on the size, is expanded to the exhaust pressure, and strikes the blades on the turbine wheel *C*. The nozzles are generally fitted with stop valves by which one or more nozzles can be cut out when the turbine is not loaded to its fullest capacity. The turbine wheel *C* is mounted on a flexible shaft *D* which is supported at the bearings *K* and *I*. After performing its work, the steam passes into the chamber *W*, and out through

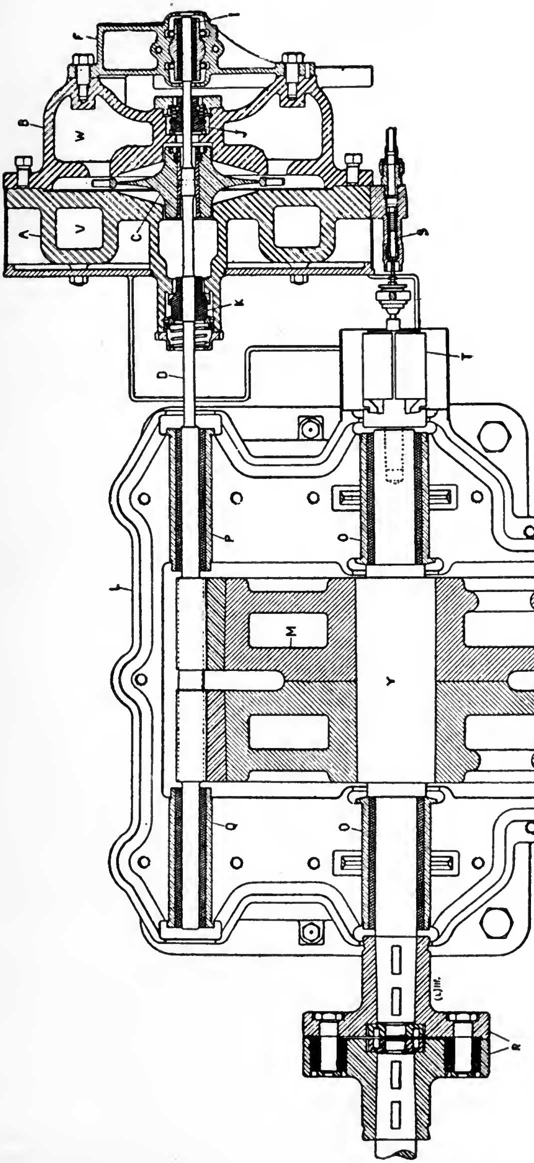


FIG. 112.—Sectional plan of the De Laval steam turbine.

the exhaust pipe into the open air or condenser. Since the total expansion of the steam takes place in one set of nozzles, the velocity of the wheel in this type of turbine is very high, and this must be reduced by gearing. The turbine shaft *D* is connected to the pinion which engages a gear wheel *M*, thus reducing the speed of the shaft *Y* to that required by the machine to be driven. A throttling governor *T* is used for speed regulation.

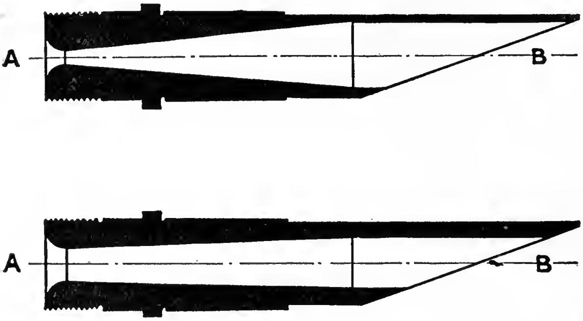


Fig. 113.—Nozzles for a De Laval turbine.

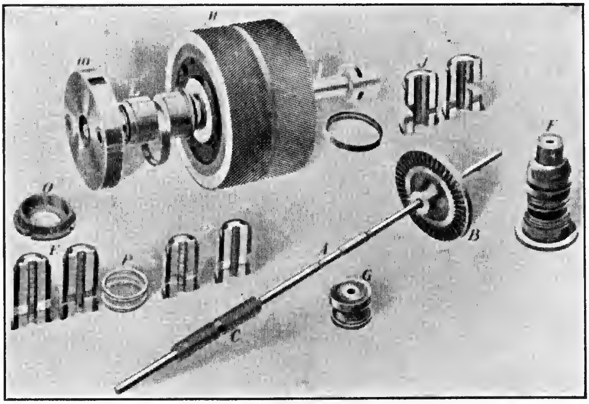


Fig. 114.—Working parts of a De Laval steam turbine.

Different nozzles are used for condensing and for non-condensing operation, as illustrated in Fig. 113. The difference in the taper of the two nozzles shows graphically the relative ratios of expansion of steam when expanding against atmospheric pressure or into a vacuum. *A* is the steam inlet and *B* is the outlet from the nozzle.

The various working parts of a De Laval turbine are illustrated in Fig. 114. A is the turbine shaft, *B* is the turbine wheel, *C* is the pinion which meshes with the gear wheel *H* to reduce the speed of the shaft *L*. *M* is a coupling which connects the shaft *I* to the machine to be driven. *D, E, F, G,* and *J* are the bearings for supporting the pinion, the flexible shaft, and the gear wheel respectively.

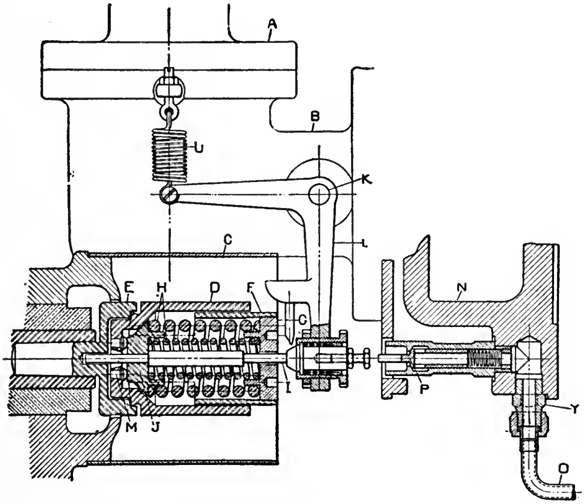


Fig. 115.—De Laval governor.

Fig. 115 shows the details of the De Laval governor. It consists of two weights *D* which are pivoted on the knife edge with hardened pins *M* which bear upon the spring seat *J*. When the speed exceeds normal, the weights, affected by centrifugal force, spread apart, pressing on the spring seat *J*, push the governor pin *I* to the right, which moves with it the bell crank lever *L*. The bell crank lever *L* operates the main admission valve, throttling the steam pressure.

When the turbine is operated condensing and overspeeds the vacuum valve *P* is operated by the governor allowing air to enter the turbine exhaust pipe, checking the turbine speed.

Velocity and Energy of Steam.—The velocity of steam issuing from a nozzle is theoretically produced by the conversion of heat energy into kinetic energy. Steam in flowing through a nozzle is reduced in pressure, and the resulting expansion releases heat energy which is utilized in accelerating the steam. The velocity resulting when steam is expanded by flowing through a perfect nozzle may be found from table 6.

Table 6 has been calculated by determining for each of the various pressures the total available energy (E) which results when steam at different conditions of quality (X) or of superheats (S) expands in a perfect nozzle. Each column represents the change of condition which results when steam at one inlet condition is expanded through the nozzle. Thus, referring to column (1), the total available energy at two different pressures represents the total energy before and after the expansion. The heat transformed into kinetic energy may then be obtained by the differences. Knowing the number of heat units available for transformation, the resulting velocity may be read directly from the scale.

As an Illustration.—Steam has a pressure of 150 pounds per square inch absolute, and is superheated 128°F. If the steam is expanded to a vacuum of 28 inches, or 1.0 pound per square inch absolute, what will be the velocity of the steam leaving the nozzle?

Solution.—Steam superheated 128°F. is found opposite the pressure of 150 pounds per square inch absolute and in column 5, Table 6.

The total heat energy of the steam (E) is indicated to be 1264 B.t.u. To find the exhaust condition, follow down column 5 until you reach the total energy opposite the 28 inch vacuum pressure. The total energy (E) for this condition is read, 922 B.t.u.

These values 1264 and 922 represent the total heat energy contained in the steam before and after the expansion. Consequently, the available heat energy utilized in creating velocity is obtained by subtracting these quantities.

$$1264 - 922 = 342 \text{ B.t.u. per pound.}$$

From the velocity scale, in connection with Table 6, 342 B.t.u.

of heat per pound corresponds to a velocity of 4120 feet per second.

The energy developed in foot pounds by the steam expanding in a nozzle can be found by multiplying 778 by the available energy E, in B.t.u., utilized in creating velocity. In the above problem, the energy developed by one pound of steam in expanding from 150 pounds absolute to 28 inches vacuum is $778 \times 342 = 266{,}076$ foot pounds.

Compound Impulse Turbines.—From the example in the previous section it is evident that steam attains a very high velocity, more than three-fourths of a mile per second, when it expands in a nozzle between a pressure of 150 pounds absolute and a vacuum of 28 inches. To utilize efficiently the energy of the steam in a turbine, in which the complete expansion of the steam occurs in one set of nozzles and the steam at high velocity is allowed to impinge against a single set of blades, the speed of the revolving blades should approximately equal one-half the velocity of the steam. A turbine operating at such a high speed cannot be utilized for direct connection to machines, but requires the interposition of a set of reducing gears.

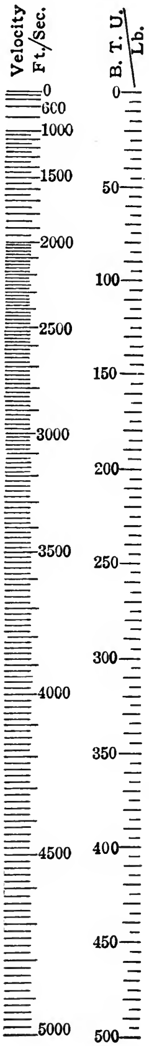
The various compound turbines have been perfected in order to do away with the reduction gearing of the simple impulse types. In the simple impulse turbine the complete expansion of the steam from boiler pressure to exhaust pressure takes place in one set of nozzles and the velocity acquired in the nozzles is given up to a single revolving wheel. In one type of compound impulse turbines the expansion of the steam takes place in a series of steps or stages, each stage being provided with a set of nozzles and a single revolving wheel. In another type, the speed is reduced by giving up the energy of the steam to several revolving wheels, the direction of the steam between the wheels being changed by stationary blades.

The Rateau Turbine.—The Rateau turbine, Fig. 116, consists of a number of stages, each stage including one row of moving blades and a set of stationary nozzles. The steam enters through the first set of stationary nozzles, in which it expands to a lower pressure with a corresponding increase in velocity, and strikes the first set of revolving blades. The steam next passes through the second set of stationary nozzles, which are of greater area

Table 6.—Guide for Determining Velocities Resulting from Expanding Steam in a Perfect Nozzle

Pressure, lb. per sq. in.		Total energy "E," and quality				
Gage	Absolute	1	2	3	4	5
235	250.0	$E=1135$ $X=0.920$	$E=1178$ $X=0.971$	$E=1220$ $S=25^\circ$	$E=1266$ $S=107^\circ$	$E=1318$ $S=206^\circ$
185	200.0	$E=1118$ $X=0.905$	$E=1160$ $X=0.955$	$E=1201$ $S=5^\circ$	$E=1240$ $S=78^\circ$	$E=1294$ $S=172^\circ$
135	150.0	$E=1096$ $X=0.887$	$E=1137$ $X=0.935$	$E=1178$ $X=0.982$	$E=1219$ $S=42^\circ$	$E=1264$ $S=128^\circ$
110	125.0	$E=1082$ $X=0.877$	$E=1122$ $X=0.922$	$E=1161$ $X=0.969$	$E=1203$ $S=22^\circ$	$E=1246$ $S=102^\circ$
85	100.0	$E=1066$ $X=0.865$	$E=1106$ $X=0.91$	$E=1145$ $X=0.954$	$E=1185$ $X=0.998$	$E=1225$ $S=72^\circ$
65	80.0	$E=1051$ $X=0.855$	$E=1090$ $X=0.898$	$E=1128$ $X=0.940$	$E=1166$ $X=0.982$	$E=1206$ $S=45^\circ$
45	60.0	$E=1031$ $X=0.842$	$E=1069$ $X=0.883$	$E=1106$ $X=0.924$	$E=1145$ $X=0.965$	$E=1182$ $S=10^\circ$
15	30.0	$E=987$ $X=0.814$	$E=1023$ $X=0.851$	$E=1058$ $X=0.888$	$E=1094$ $X=0.926$	$E=1129$ $X=0.964$
atmospheric 0	15.0	$E=946$ $X=0.790$	$E=979$ $X=0.823$	$E=1013$ $X=0.858$	$E=1043$ $X=0.893$	$E=1080$ $X=0.928$
in. mercury vacuum 10	10.0	$E=923$ $X=0.776$	$E=955$ $X=0.809$	$E=988$ $X=0.842$	$E=1020$ $X=0.876$	$E=1053$ $X=0.908$
20	5.0	$E=886$ $X=0.756$	$E=916$ $X=0.786$	$E=948$ $X=0.818$	$E=979$ $X=0.849$	$E=1010$ $X=0.880$
24	3.0	$E=860$ $X=0.742$	$E=890$ $X=0.772$	$E=921$ $X=0.802$	$E=950$ $X=0.831$	$E=980$ $X=0.861$
26	2.0	$E=840$ $X=0.731$	$E=870$ $X=0.760$	$E=899$ $X=0.789$	$E=928$ $X=0.818$	$E=958$ $X=0.847$
28	1.0	$E=810$ $X=0.716$	$E=837$ $X=0.742$	$E=865$ $X=0.769$	$E=894$ $X=0.797$	$E=922$ $X=0.823$
29	0.5	....	$E=806$ $X=0.726$	$E=833$ $X=0.751$	$E=860$ $X=0.777$	$E=888$ $X=0.802$

"X" or superheat "S"				
6	7	8	9	10
$E=1314$ $S=230^\circ$				
$E=1294$ $S=198^\circ$				
$E=1270$ $S=162^\circ$				
$E=1244$ $S=129^\circ$	$E=1297$ $S=228^\circ$			
$E=1222$ $S=68^\circ$	$E=1266$ $S=180^\circ$			
$E=1164$ $X=1.00$	$E=1202$ $S=60^\circ$			
$E=1114$ $X=0.963$	$E=1148$ $X=0.997$	$E=1221$ $S=100^\circ$		
$E=1186$ $X=0.943$	$E=1118$ $X=0.975$	$E=1186$ $S=94^\circ$		
$E=1041$ $X=0.911$	$E=1172$ $X=0.942$	$E=1134$ $S=9^\circ$	$E=1168$ $S=82^\circ$	
$E=1010$ $X=0.890$	$E=1040$ $X=0.920$	$E=1100$ $X=0.979$	$E=1130$ $S=20^\circ$	
$E=987$ $X=0.875$	$E=1015$ $X=0.913$	$E=1075$ $X=0.961$	$E=1105$ $X=0.990$	$E=1036$ $S=45^\circ$
$E=950$ $X=0.851$	$E=978$ $X=0.878$	$E=1034$ $X=0.932$	$E=1062$ $X=0.959$	$E=1090$ $X=0.987$
$E=914$ $X=0.828$	$E=941$ $X=0.854$	$E=995$ $X=0.905$	$E=1022$ $X=0.931$	$E=1049$ $X=0.957$



Velocity Scale

than the first, because the volume of steam was increased by its expansion in the first set. Here the steam again expands and enters the second row of moving blades, and the process is repeated in succeeding stages until the steam reaches the exhaust outlet.

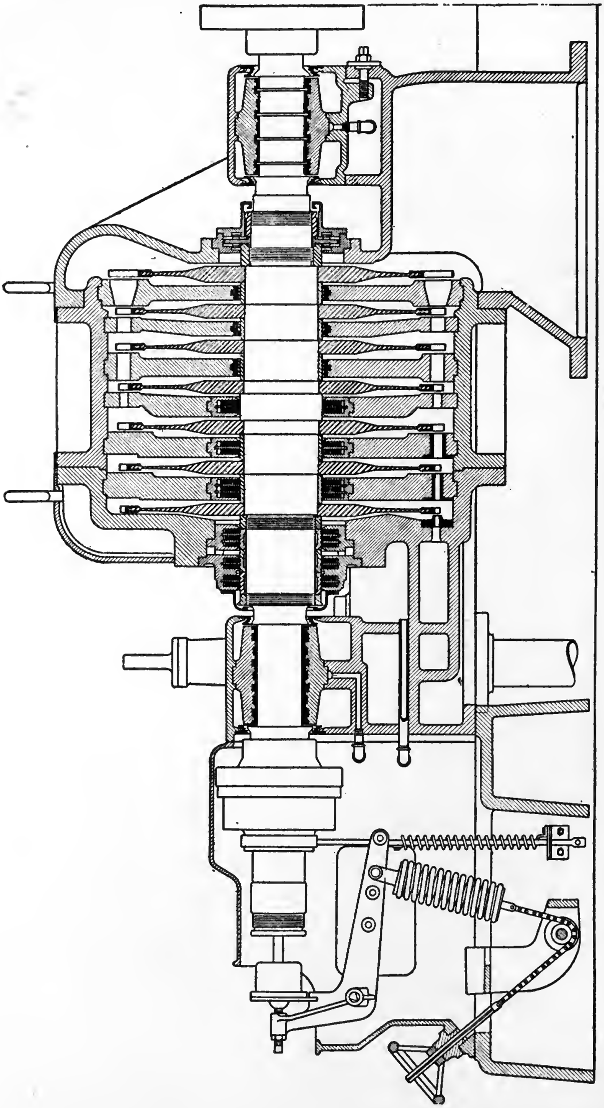


Fig. 116.—Rateau steam turbine.

The Kerr Turbine.—The Kerr steam turbine, illustrated in Fig. 117, is similar to the Rateau in that the expansion of the steam takes place in a series of stages, each stage being provided with a set of nozzles and a single revolving wheel. The expansion in a Kerr turbine is carried out in from six to ten stages. The steam is partly expanded in the first set of nozzles, and the energy developed is abstracted by the first revolving wheel. The steam then expands in a second and subsequent set of nozzles until the steam from the last revolving wheel enters the exhaust.

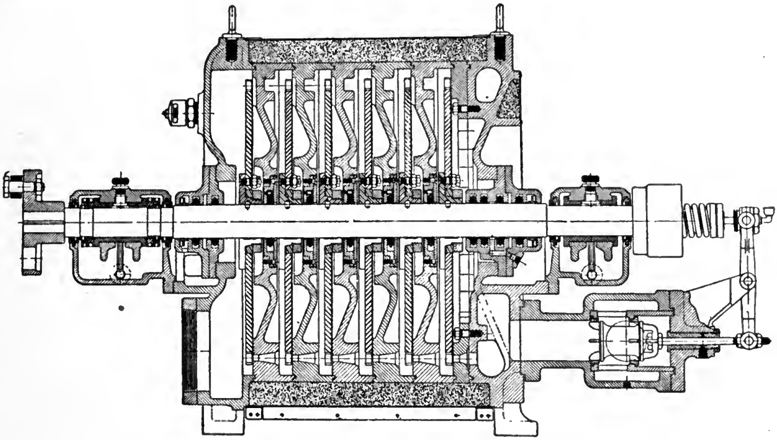


Fig. 117.—Kerr steam turbine.

A single stage simple impulse turbine with double cup-shaped blades is illustrated in Fig. 118. This type of turbine was formerly manufactured by the Kerr Company.

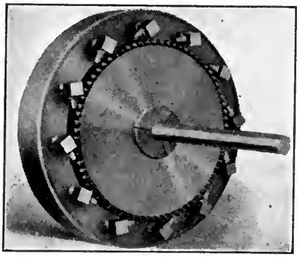


Fig. 118.—Turbine with double cup-shaped blades.

The Kerr steam turbine is governed by a centrifugal spring-loaded throttling governor mounted directly on the turbine shaft, and acting through suitable connections upon the steam valve stem. An emergency governor, entirely independent of the main governor, shuts down the turbine, when it overspeeds, by closing a valve in the steam line.

De Laval Multiple Impulse Turbine.—The De Laval multiple impulse turbine is illustrated in Fig. 119. It consists of a series of blade wheels which revolve in independent chambers formed between diaphragms held in the casing of the turbine. Steam is admitted to the steam chest at the right hand end of the turbine and is directed by means of nozzles upon the blades of the first revolving wheel. The steam leaving the first revolving wheel passes through guide blades, which are set around the entire periphery of the diaphragm separating the first and second stages, and strikes the blades of the second revolving wheel, and so on through the succeeding stationary and revolving blades.

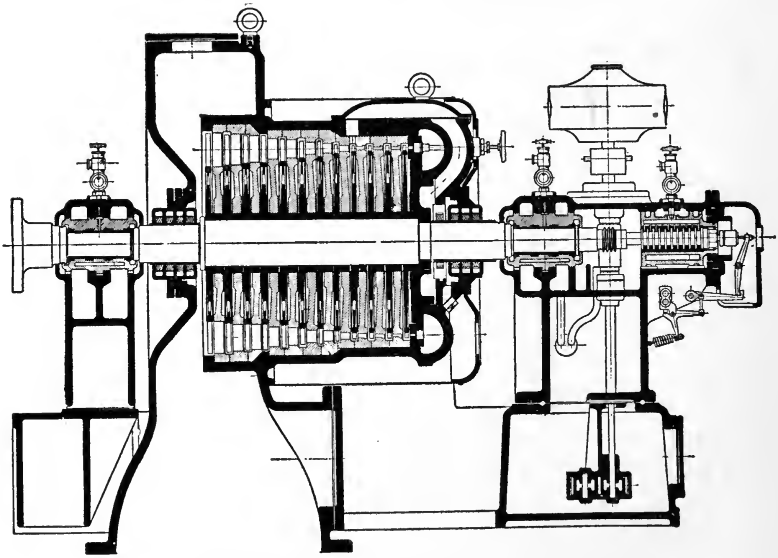


Fig. 119.—De Laval multiple-impulse steam turbine.

The governing of the De Laval Multiple impulse turbine is accomplished by throttling the admission of the steam to the steam chest. An emergency governor is mounted in the end of the turbine shaft, entirely independent of the main speed governor, and can be adjusted to act at any predetermined speed.

De Laval multiple impulse machines are provided with reduction gears for the driving of machines at slow speeds.

The Terry Turbine.—The principle of the Terry turbine is illustrated in Fig. 120. This turbine consists of one set of nozzles and one revolving wheel. The steam is expanded in the nozzle from approximately boiler pressure to exhaust pressure. The jet of steam issuing from the nozzle *N*, at high velocity, strikes the side of the wheel blades, is reversed in direction 180 degrees, and is guided into one of the stationary reversing blades *R*, by means of which the jet is redirected a second time on the buckets *B* of the wheel. This process is repeated several

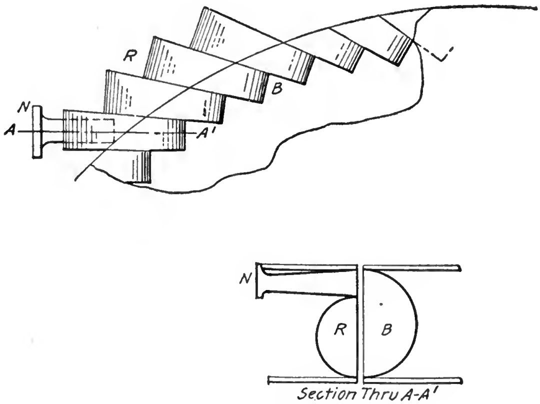


FIG. 120.—Terry steam turbine.

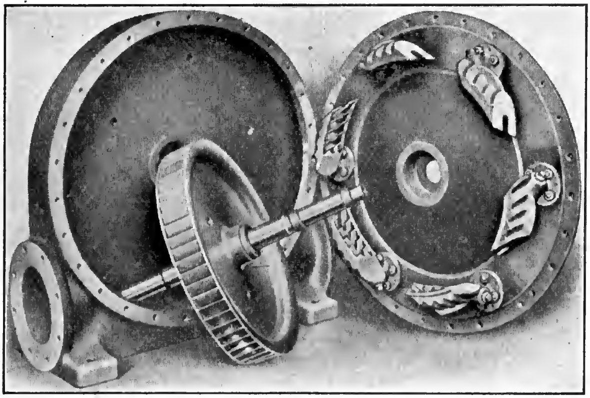


FIG. 121.—Parts of a Sturtevant turbine.

times until all the available energy of the steam has been abstracted by the revolving element.

The Sturtevant Turbine.—The Sturtevant turbine (Fig. 121) is similar to the Terry turbine in that the steam from the moving blades is diverted back into the stationary blades next to the nozzle. A sectional view through a Sturtevant turbine is shown in Fig. 122. A throttling governor is used to regulate the speed of this turbine.

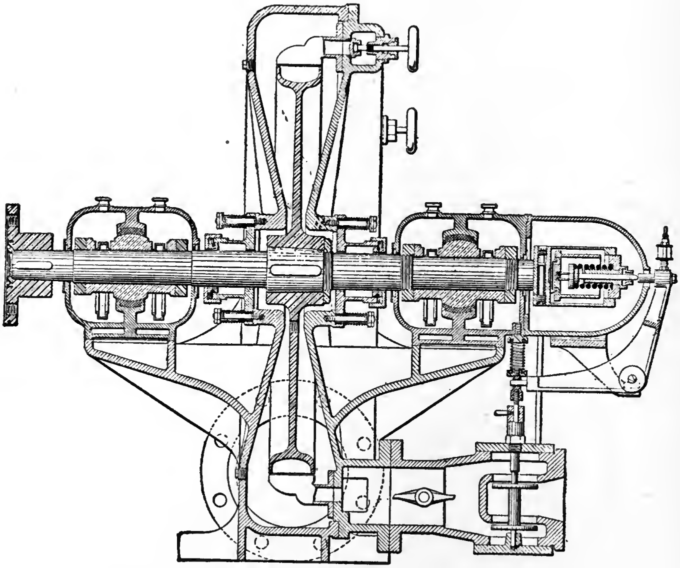


Fig. 122.—Sectional view of a Sturtevant turbine.

The Westinghouse Impulse Turbine.—The Westinghouse impulse turbine operates on the same principle as the Sturtevant and Terry turbines.

The Curtis Steam Turbine.—In the Curtis steam turbine, the expansion of the steam takes place in several stages and the velocity acquired in the nozzles of each stage is abstracted by one or two revolving wheels. The number of stages varies from four to nine or more, depending upon the size of the machine. In very small sizes the Curtis turbine is built as a one stage machine, with two or three revolving wheels.

The action of the Curtis turbine is illustrated by Fig. 123. Steam at boiler pressure enters through one or more admission valves *B* into the steam chest *C*. The steam from the steam chest enters the expanding nozzles *D*. The number of admission valves used is controlled by the governor in accordance with the load. The steam jet at high velocity issuing from the nozzle *D* strikes the moving blades *F*, giving up a portion of its energy. The direction of the steam is changed by the stationary or guide blades *G*, called intermediates, striking the second set of moving

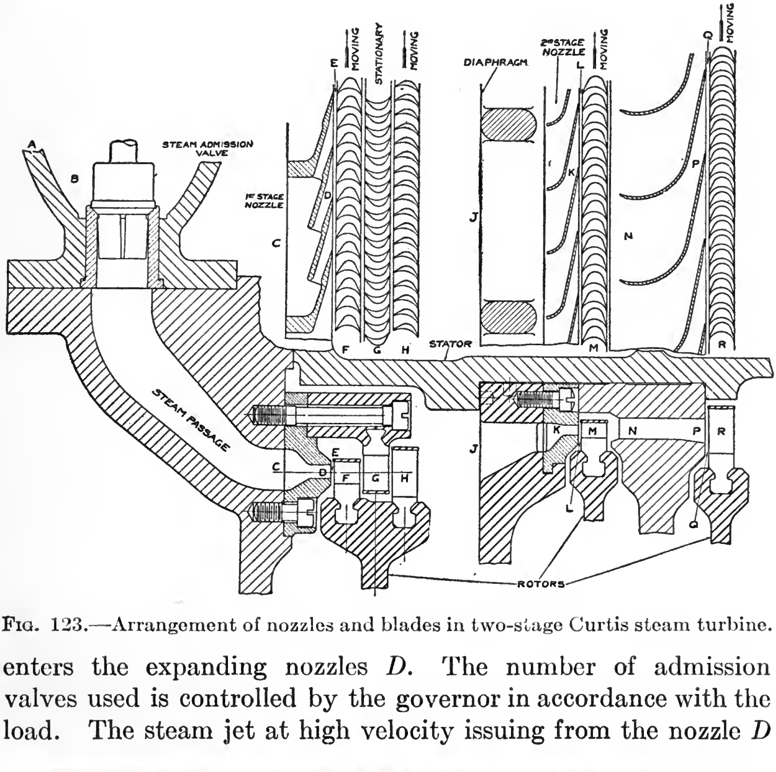


FIG. 123.—Arrangement of nozzles and blades in two-stage Curtis steam turbine.

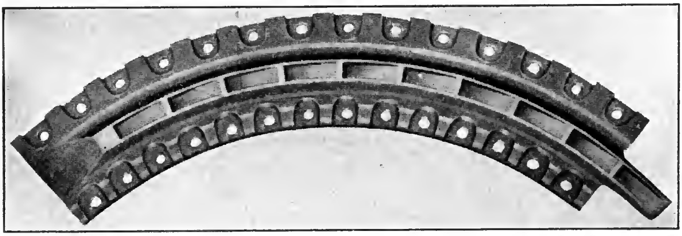


FIG. 124.—First stage nozzle plate for a Curtis turbine.

blades *H*. The steam issuing from the second set of moving blades enters the second stage, where it is further expanded by means of nozzles *K* and the energy developed is abstracted by moving blades *M*. The same operation is repeated in the third and in the subsequent stages.

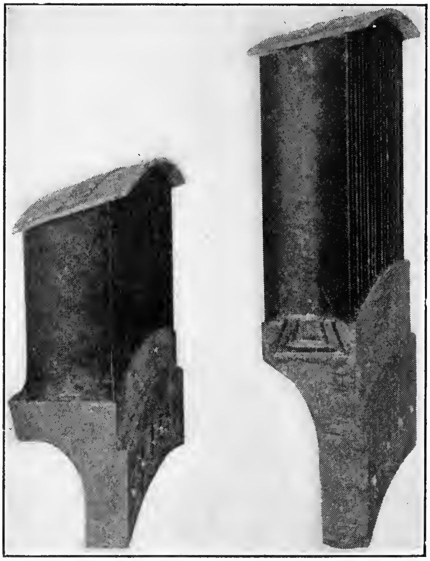


Fig. 125.—Blading of Curtis turbine.

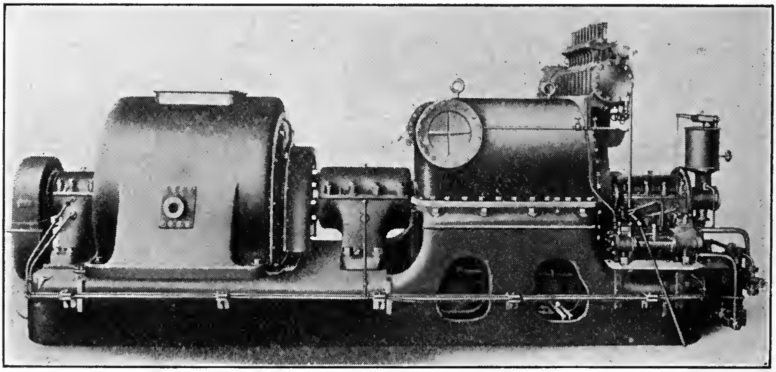


Fig. 126.—Horizontal Curtis steam turbine.

The expanding nozzles of the first stage of a Curtis turbine are illustrated in Fig. 124. These extend around a relatively short arc of the periphery in the first stage, while in the low pressure end they extend around the entire wheel.

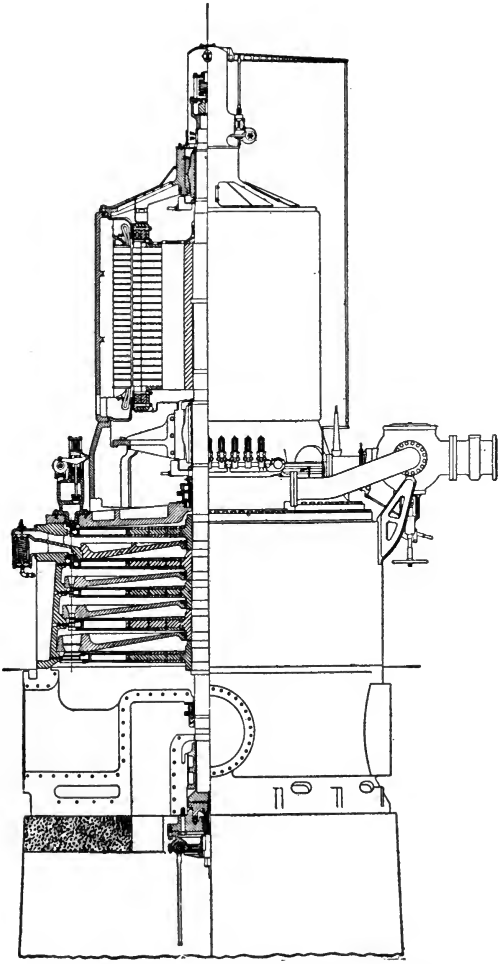


FIG. 127.—Vertical Curtis steam turbine.

The method used in fastening blades of a Curtis turbine is illustrated in Fig. 125.

The Curtis turbine is constructed as a horizontal machine

(Fig. 126). The vertical arrangement (Fig. 127), used in some of the earlier designs, is now obsolete, but units of this type can still be found in operation in many of the large power plants. In the vertical turbines the shaft is supported by a step-bearing at the lower end. Oil is pumped under this bearing at considerable pressure, thus floating the entire revolving element on an oil film.

Small Curtis turbines are controlled by means of a throttling governor. Large turbines are controlled by an indirect type of governor, which mechanically or through a pilot valve and a hydraulic cylinder opens or closes the admission valves, thus regulating, in accordance with the load, the number of nozzles which are open for the discharge of steam. The hydraulic type of governor for Curtis turbines is illustrated in Fig. 128.

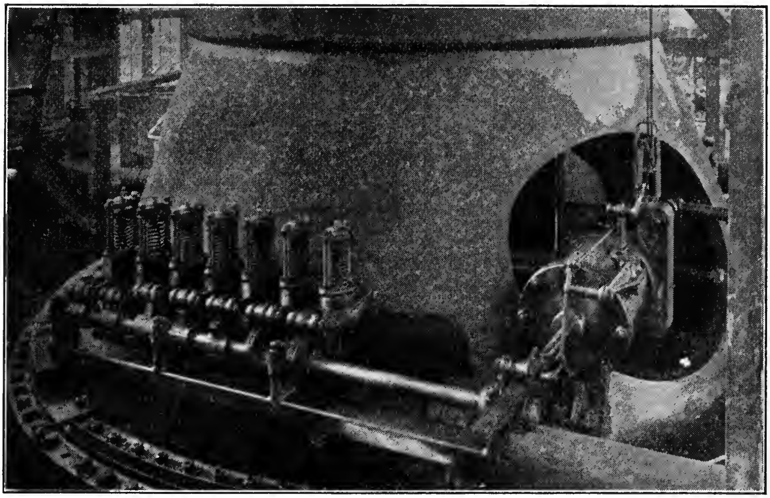


Fig. 128.—Hydraulic governor for Curtis turbine.

Curtis turbines are equipped with an automatic emergency governor, independent of the main governor, which through a trip operates the main throttle valve when the turbine speed exceeds a predetermined limit.

The Reaction Turbine.—The reaction steam turbine differs from the impulse turbines in that stationary blades are substituted for nozzles. The blades are shaped so that they can per-form the functions of the nozzles and of the blades of impulse turbines. The reaction turbine has many stages, each stage consisting of a set of stationary and of rotating blades. Part of the expansion of the steam takes place in the stationary blades and part in the moving blades. In the impulse turbine the pressure on both sides of the moving wheel is very nearly the same; in the reaction turbine the pressure at the inlet to the wheel blade is greater than the pressure at the outlet.

The Parsons Turbine.—The principle of the single flow Parsons reaction turbine is illustrated in Fig. 129.

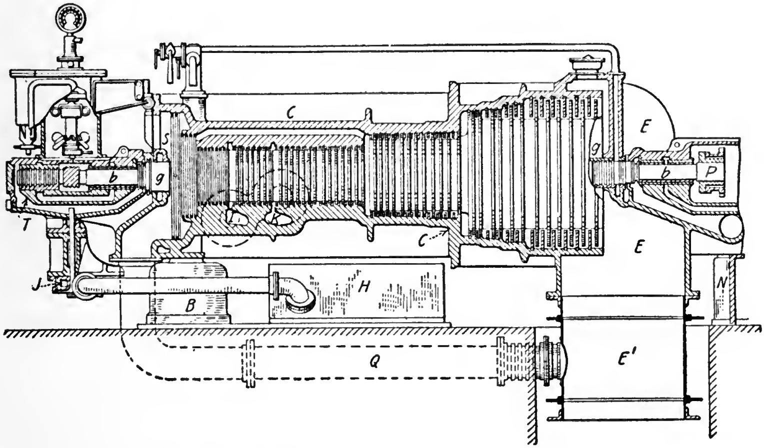


FIG. 129.—Sectional view of a Parsons turbine.

The steam enters a governor valve, reaches the chamber *I* and passes out to the right through the turbine blades, eventually arriving at the exhaust chamber *E*. The areas of the passages increase progressively in volume, corresponding with the expansion of the steam.

The rotating part of the turbine consists of a long drum upon which are mounted the moving blades. The stationary or guide blades are fitted in rings fastened to the turbine casing.

On the left of the steam inlet are shown the revolving balancing pistons, one corresponding to each cylinder or section of the turbine. The steam at *I* presses against the turbine and goes through doing work. It also presses in the reverse direction, but cannot pass the piston, thus equalizing the pressure and reducing end thrust on the shaft. In most designs of Parsons turbines all the balancing pistons are at the pressure end of the turbine. In the Allis-Chalmers Parsons turbine the largest balancing piston is placed at the low pressure end of the rotating element behind the last row of blades.

At *T* is shown a thrust bearing which serves to maintain the correct adjustment of the balancing pistons. *Q* is a pipe connecting the back of the balancing piston at *S* with the exhaust chamber *E′*, to insure that the pressure at this point should be the same as that of the exhaust. The governor gear and oil pumps generally receive their motion by means of a worm wheel, gearing into a worm cut on the outside of the coupling. An oil reservoir is provided into which drains all the oil from the bearings. From there it flows to a pump to be pumped to a chamber, where it forms a static head which gives a continuous pressure of oil to the bearings. A by-pass valve is provided, this valve admitting high-pressure steam to the lower stages. By opening this valve the turbine can carry considerable overload or to operate non-condensing at nearly full load.

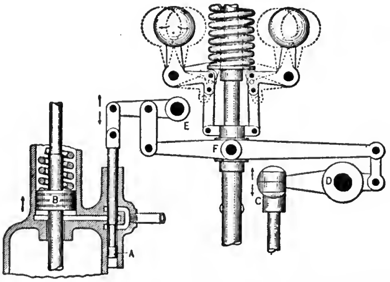


Fig. 130.—Governor for Parsons turbine.

Reaction turbines are controlled by an indirect type of governor, which causes the main steam admission valve to remain open for longer or shorter periods of time, depending upon the load carried by the machine. The governor is of the fly ball type and is illustrated diagrammatically in Fig. 130.

The governor levers (Fig. 130) are attached to the small relay valve which operates the main admission valve. The levers receive reciprocating motion at *C* from an eccentric and use the governor clutch as a fulcrum, points *D* and *E* being fixed. Continuous reciprocating motion is thus given to the relay valve. This is in turn transmitted to the admission valve. The function of the governor is to vary the plane of oscillation of the relay valve, which causes the admission valve to remain open for a longer or shorter period, according to the position of the governor.

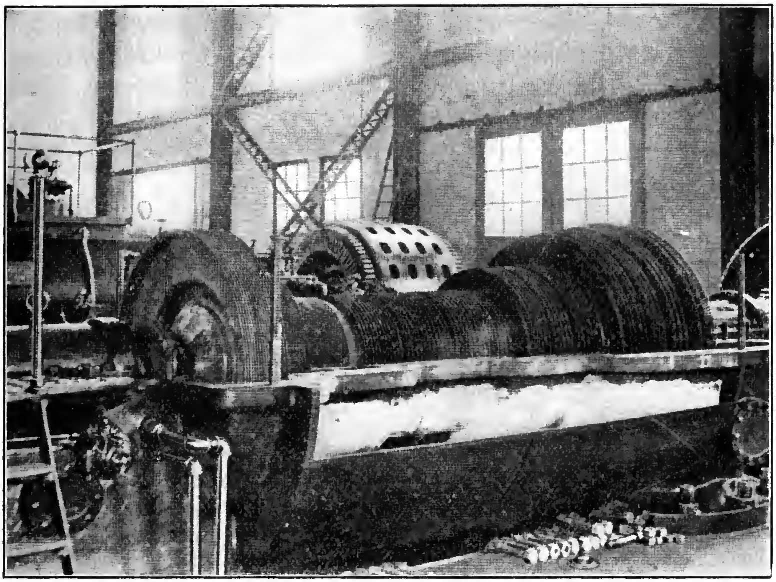


Fig. 131.—Westinghouse-Parsons turbine with the upper casing removed.

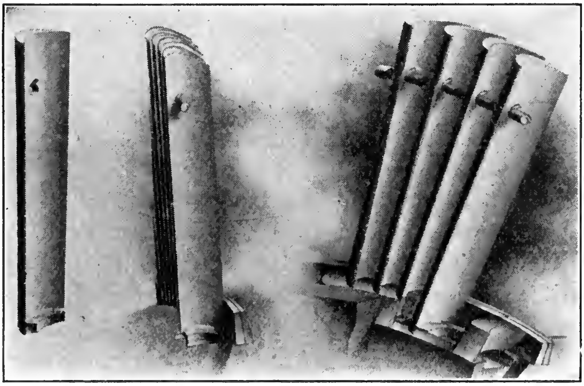


Fig. 132.—Blading of Westinghouse-Parsons turbines.

Thus the steam is admitted in puffs, which occur at constant intervals of time. The puffs are either of long or short duration according to the load. At heavy loads the puffs merge in a continuous blast. With this type of governor high-pressure steam is used at all loads.

A Westinghouse-Parsons turbine with its upper casing removed is illustrated in Fig. 131. The method used in fastening the blades of a Westinghouse-Parsons steam turbine is illustrated in Fig. 132.

The Impulse-reaction Turbine.—A section through a combined impulse and reaction turbine is shown in Fig. 133. The impulse element is similar to the first stage of a Curtis turbine, and consists of one set of nozzles, an impulse wheel with two rows of revolving blades, and a set of stationary blades. Steam first enters the turbine nozzles, is partly expanded, and impinges upon the impulse blades. The remaining energy of the steam after leaving the impulse blades is utilized in the reaction element of the turbine.

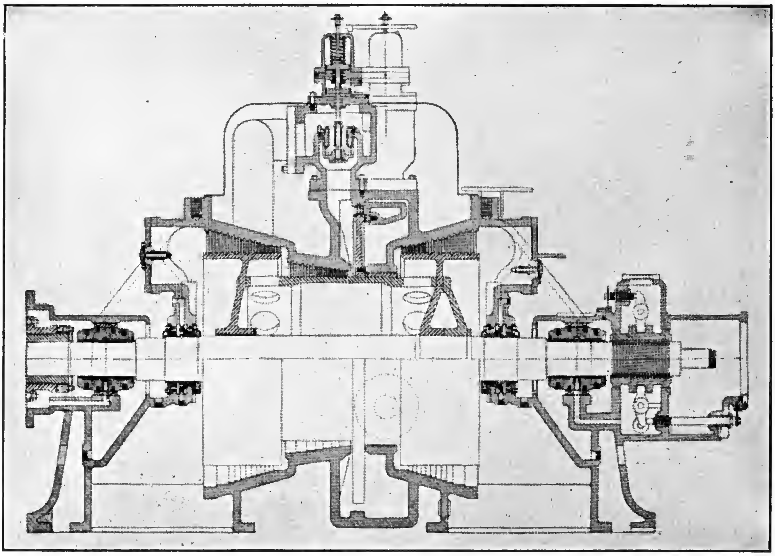


Fig. 133.—Double-flow Westinghouse turbine.

The impulse-reaction turbine occupies less space than the pure reaction machine. It is constructed either as a single flow or as a double flow machine. In the single flow the reaction elements are on one side of the impulse stage, while in the double flow (Fig. 133) the reaction elements are on both sides of the impulse wheel.

The Spiro Steam Turbine.—The Spiro steam turbine, which is illustrated in Figs. 134 and 135, consists of two herringbone gears in mesh which revolve in a close-fitting casing. Steam is admitted at mid-length into the tooth pockets at the point *A* of each rotor. As the rotor turns, the tooth space occupied by the steam increases in length and the steam expands. The steam escapes when the outer ends of the teeth pass the line of contact between the two rotors. The inlet port openings are situated one on each side of the central rib, as illustrated in Fig. 135. This turbine is governed by throttling the steam.

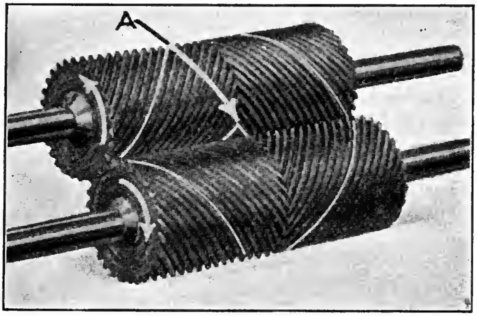


Fig. 134.—Rotors of the Spiro turbine.

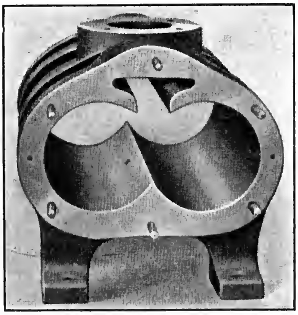


Fig. 135.—Casing or cylinder of the Spiro turbine.

The Spiro steam turbine is not suitable for condensing operation, but is compact and is used for the driving of pumps, fans, and other auxiliaries in connection with power plants, office buildings, and factories.

Exhaust Steam Turbines.—A steam turbine installed between the exhaust of a reciprocating engine and a condenser is called an exhaust steam turbine. The reciprocating steam engine does not show as high an economy at high vacuum as does the steam turbine. The capacity and economy of reciprocating engine steam power plants have been increased by the addition of a low pressure turbine.

Exhaust steam turbines may be operated as straight low pressure turbines using only exhaust steam from engines, or as mixed pressure turbines which operate on high and low pressure steam at the same time.

Ordinarily, combined reciprocating engines and low pressure steam turbines would not be selected for a new installation, as the cost of the combined units is much greater than that of the high pressure steam turbine. The field of the low pressure steam turbine is in connection with the large non-condensing reciprocating engine power plant.

Applications of the Steam Turbine.—The steam turbine is applicable to work which requires a high and constant rotative speed, where a high starting effort is not required, and where there is no need of reversing the direction of motion. These conditions exist in electric generating stations. For service in which the speed is low and variable, where a reversal of direction is necessary, or where the starting torque is high, the turbine is unsuited and the reciprocating engine is better adapted. Speed-reduction and reversing gears have been employed in connection with turbines, but these have only a limited application.

The steam turbine is very seldom operated non-condensing; in power plants where the exhaust steam is used for heating or for manufacturing purposes the reciprocating engine will usually be found more satisfactory.

Steam turbines are used to some extent for the driving of power plant auxiliaries, such as boiler feed pumps, hot well pumps and circulating pumps; also high pressure fans and blowers.

Steam turbines are also employed for the propulsion of ships.

The steam turbine has less weight and requires less space than the reciprocating engine of the same size. Vessels propelled by steam turbines are more stable on account of the lower center of gravity of the machinery. The steam turbines are usually connected to the propellers by means of gears. In some cases the steam turbine drives an electric generator and the propellers are driven by electric motors, which receive their current from the generator of the turbine.

Steam Turbine Economy.—The economy of steam turbines is usually expressed in pounds of steam per kilowatt hour, as the greatest field of the turbine is for the driving of electric generators. Steam turbines in sizes of 1,000 to 10,000 kilowatt, when operated at 150 to 200 pounds gage pressure, with superheats of 100° to 200°F. and with a vacuum of 28 to 29 inches, will develop a kilowatt on 12 to 15 pounds of steam per hour. Better economies are secured as the size of the unit increases. The smaller condensing steam turbines, when operated with saturated steam, will consume 18 to 30 pounds of steam per kilowatt per hour. Steam turbines when operated non-condensing will consume 50 to 75 pounds of steam per kilowatt per hour.

Steam turbines under ordinary operating conditions will show a gain of about 8 per cent. for each 100 degrees superheat. The presence of moisture will decrease the economy or increase the steam consumption by about 2 per cent. for 1 per cent. of moisture in the steam. Increasing the vacuum from 27 to 28 inches will increase the turbine economy from 3.0 to 5 per cent. Increasing the steam pressure from 150 to 200 pounds will increase the economy about 3 per cent.

Installation and Care of Steam Turbines.—The general rules given in Chapter VII concerning the installation and care of reciprocating steam engines apply also to steam turbines.

The steam turbine should be located so that it will be accessible from all sides for inspection and repair. Proper crane and hoist facilities should be available for all parts which are too heavy to be handled by hand.

The foundation should be sufficiently heavy to afford a permanent support and rigid enough to prevent springing or warping any part of the turbine. To prevent vibrations from being conducted to the building, a space should always be left between the turbine foundation and the walls or floors; this space should be filled with some soft material. After the foundation is properly set, care must be taken to obtain proper adjustment of the turbine. Small steam turbines are usually placed on concrete floors without foundations.

The piping must be so designed and installed that no strain will be thrown on the turbine due to expansion and contraction, or on account of the piping being improperly supported. Water pockets in the piping should be avoided.

Before starting a steam turbine for the first time, care must be taken to blow out the steam and oil from the piping in order to remove scale and dirt. The oiling system should then be put in operation and the turbine should be warmed up and started slowly, listening for any clicking or rubbing sounds, which may require investigation. While the turbine is turning over slowly the oiling system and the auxiliaries should be examined. Heating of the bearings may be due to grit or to poor alignment. After ascertaining that everything is in good working order, the turbine should gradually be brought up to speed. As the turbine approaches full speed, the action of the governor should be observed. If the governor is working properly, the turbine is ready for the load.

In starting a condensing turbine, the condenser auxiliaries are started first, and after the vacuum has been obtained, the turbine is started.

Problems

1. To gain a conception as to the enormous amount of power a 70,000 kilowatt turbine develops, calculate the following:

(*a*) If all the energy of a 70,000 kilowatt turbine is used to supply light, calculate the number of candle power it will supply by means of Tungsten lamps.

(*b*) If a 70,000 kilowatt turbine develops a kilowatt on 2½ pounds of coal per hour, calculate the amount of fuel required to keep such a turbine in operation at full load for ten hours.

2. Calculate, using Table 6, the energy in foot pounds which will be developed when steam, initially 2 per cent. wet, expands in a perfect nozzle:

(*a*) From 150 pounds absolute to atmospheric,

(*b*) From 150 pounds absolute to 28 inches vacuum.

3. Calculate and compare the velocities developed by:

(*a*) Water falling through a head of 200 feet.

(*b*) Steam, initially dry, expanding in a perfect nozzle from a steam pressure of 200 pounds absolute to a vacuum of 29 inches.

4. Show by means of clear sketches the details of governors used in connection with:

(*a*) Simple impulse turbines,
(*b*) Curtis turbines,
(*c*) Parsons turbines.

5. Explain how vessels propelled by steam turbines are reversed.

CHAPTER IX

ENGINE AND TURBINE AUXILIARIES

Many of the auxiliaries which properly belong to the engine and turbine have been described in Chapters IV, V, VI, VII, and VIII. This chapter will deal mainly with condensers and condenser auxiliaries, but will include other apparatus which can be called auxiliaries or accessories to an engine or turbine.

CONDENSERS

The Principle of the Condenser.—The advantage gained by operating a steam engine condensing is due to the reduction in the back pressure against which the engine exhausts. In the case of the steam turbine, the available energy in the steam can be more than doubled by carrying high vacua, as compared with non-condensing operation.

The gain in economy which can be expected by increasing the vacuum depends to some extent upon the size of engine or turbine, and also upon the type of machine. The theoretical gain for a perfect steam motor per inch of vacuum will vary from about 3.0 per cent. at 25 inches vacuum to about 5.0 per cent. at 28 inches vacuum. A well designed steam turbine will very nearly realize the theoretical gains for any given vacuum. A high vacuum means low temperature condensed steam, and this may necessitate the heating of condensed steam before it is used as boiler feed water.

If an engine or turbine is provided with some vessel into which the steam is exhausted, vacuum could be maintained by simply removing the uncondensed exhaust steam as fast as it enters. Such a method, however, would not be economical, as the equipment utilized in maintaining the vacuum would have to handle practically the entire volume of exhaust steam leaving the engine. If this were the case, very little gain would result, for as much work would have to be done by the condenser pump in maintaining the lower back pressure as would be gained by the engine.

Steam, however, may easily be condensed, and in the form of water occupies a very much smaller volume. Advantage of this fact is taken in the operation of condensers. Thus, if the exhaust steam from the engine is admitted into a vessel and condensed before being discharged, the work required to maintain the vacuum is greatly reduced, because the work of the condenser pump is only that due to the removal of a comparatively small volume of water.

In a system composed entirely of steam, or one in which the exhaust steam was not mixed with air or with other gases which have entered the system, the vacuum to be maintained is dependent upon the temperature of the condensed steam. By reference to the steam tables (Table 5), it will be found that water at a temperature of 126.1 degrees Fahrenheit boils at a pressure of 2 pounds absolute. A condenser in which the condensed steam is at that temperature would be limited to that pressure. Any attempt to lower the vacuum would cause an evaporation of the condensed steam.

In the actual operation of condensers the temperature of the condensed steam must be below that corresponding to the vacuum to be carried. The condenser is never free from air and the temperature of the condensed steam is several degrees below that corresponding to the vacuum carried. Air enters with the boiler feed water and also leaks in the condenser through piping and valves. The air mixed with the steam not only tends to destroy the vacuum and raise the pressure in the condenser above that theoretically required, but must also be continuously removed, if the vacuum is to be maintained.

The Measurement of Vacuum.—The pressure maintained in a condensing system may be measured by a mercury manometer or by a special gage. The pressure is below that of the atmosphere, hence the term vacuum is applied.

The measurement of pressures above that of the atmosphere is expressed in pounds gage. In the measurement of pressures below atmosphere, the unit of pressure is usually stated in inches of mercury and expresses the amount of pressure below that of the atmosphere. To convert pressure above atmospheric to absolute pressure, the gage pressure is added to the atmospheric pressure, corresponding to the barometric reading. When vacuum readings have to be converted into absolute pressures, the pressure corresponding to the vacuum must be deducted from the atmospheric pressure.

As an illustration, a condensing engine receives steam at 100 pounds per square inch gage and exhausts into a condenser whose gage reads 26 inches of mercury. The barometric pressure is 29 inches of mercury.

A column of mercury 1 inch high is equivalent to a pressure of 0.491 (roughly $\frac{1}{2}$) pounds per square inch, or the equivalent pressure of the atmosphere is then:

$$29 \times 0.491 = 14.24 \text{ pounds per square inch.}$$

The absolute pressure of the entering steam is:

$$100 + 14.24 = 114.24 \text{ pounds per square inch.}$$

Since the vacuum in the condenser is measured in units below atmospheric pressure the absolute pressure within the condenser is:

$$29 - 26 = 3 \text{ inches of mercury}$$

which is equivalent to·

$$3 \times 0.491 = 1.47 \text{ pounds per square inch absolute.}$$

Types of Condensers.—Condensers are either of the jet or of the surface type. The jet condensers produce condensation by the direct mingling of the exhaust steam and circulating water, and the resulting mixture of condensed steam and water leaves the condenser at the same temperature. In the surface condenser, the exhaust steam and the circulating water are separated by tubes, the heat transfer between the steam and circulating water taking place by conduction through the tubes.

The jet condenser is much simpler than the surface condenser and its first cost is lower, but in most cases it is restricted in its application to plants where the injection water is good. The surface condenser has the advantage in that its cooling water does not come in direct contact with the steam to be condensed. For this reason surface condensers are used where the condensed steam is returned to the boiler, and where the cooling water is salty, muddy, or otherwise unfit for steam making. While the surface condenser is particularly well suited for plants where the circulating water is poor, it must not be inferred that it would be practical to use water so filthy that it would foul the tubes.

Jet Condensers.—Fig. 136 illustrates the construction of one of the simpler types of jet condensers. Exhaust steam enters at *A*. Injection water enters at *B*, and is divided into a fine spray by the adjustable valve *D*. The steam is condensed by contact with the finely sprayed water, and the mixture accumulates in chamber *F*, from which it passes to the pump *G* and is discharged at *J*. The pump *G* in this type of condenser must remove both the air and the condensed steam. It is called a wet air pump. The pump cylinder in order to handle the air and the condensed steam must be designed larger than would be required for the removal of the water alone.

Injection water under pressure is not necessary with this type of condenser, as the water will be drawn into the condensing chamber by the vacuum produced, although the pumping head in such cases is limited to about 15 feet. With such an arrangement, means must be provided for creating a vacuum when starting the condenser. This is usually accomplished by starting the pump or by providing the condenser with an auxiliary supply of injection water under pressure, which will produce sufficient vacuum by condensing the first steam admitted.

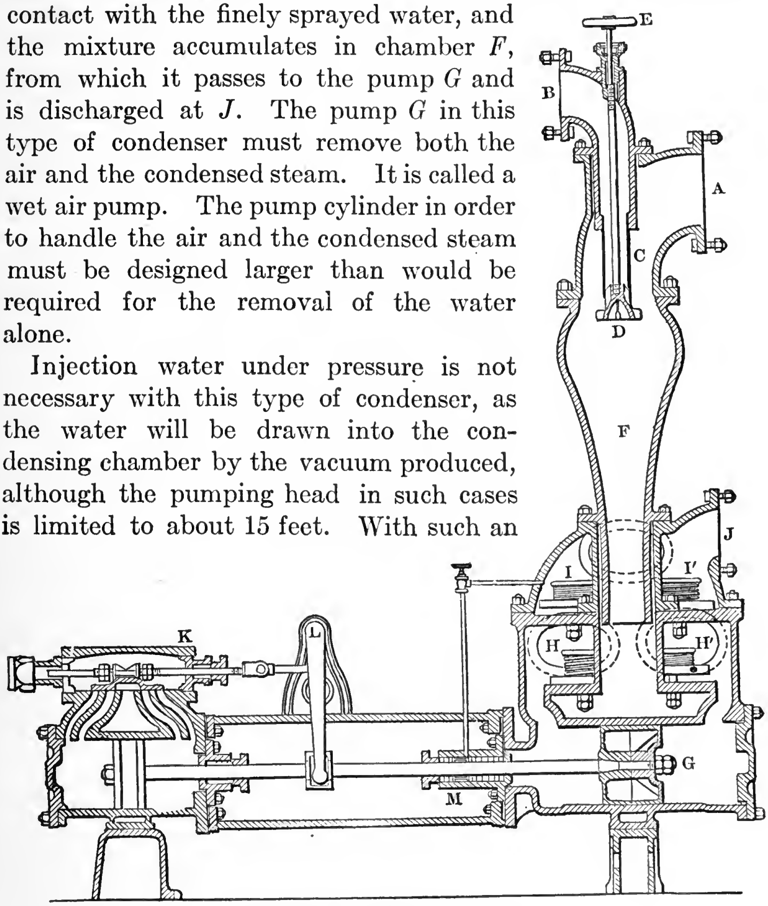


FIG. 136.—Jet condenser.

Condensers are usually provided with some means for automatically breaking the vacuum. The atmospheric relief valve, illustrated in Fig. 137, is placed in a branch taken from the main exhaust line between the condenser and the engine, and leading to the atmosphere. The atmospheric exhaust valve is held closed by the atmospheric pressure when the vacuum is maintained, but should the vacuum be lost the pressure of the exhaust steam operates the valve, permitting a free outlet of the steam to the atmosphere. When the vacuum is restored, the valve will automatically close.

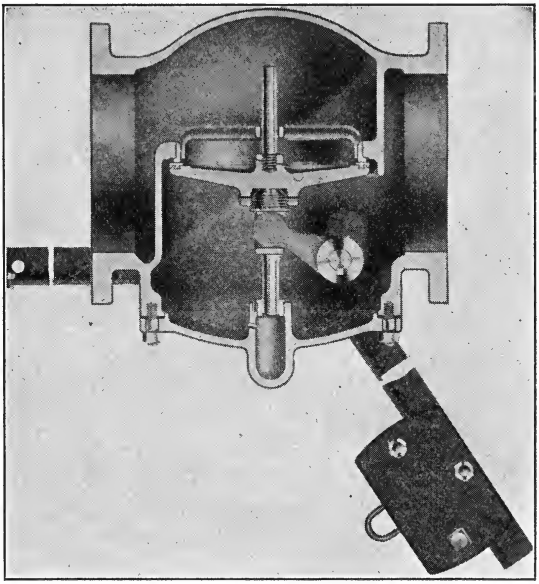


Fig. 137.—Atmospheric relief valve.

Barometric Condensers.—Fig. 138 illustrates the barometric type of jet condenser. The condensing chamber is supported upon a water-sealed tail pipe, 34 feet above the surface of the water in the hot well. Atmospheric pressure at sea level will support a column of water 34 feet high, consequently the accumulation of condensed steam in the tail pipe which would tend to rise above this height, will displace an equal quantity of water from the bottom of the tail pipe. No pump is required for the removal of the condensed steam from the barometric condenser, but in most cases the use of a pump for the injection water is necessary. If the cold water supply is within a vertical distance of 20 feet from the injection opening to the condenser, the use of

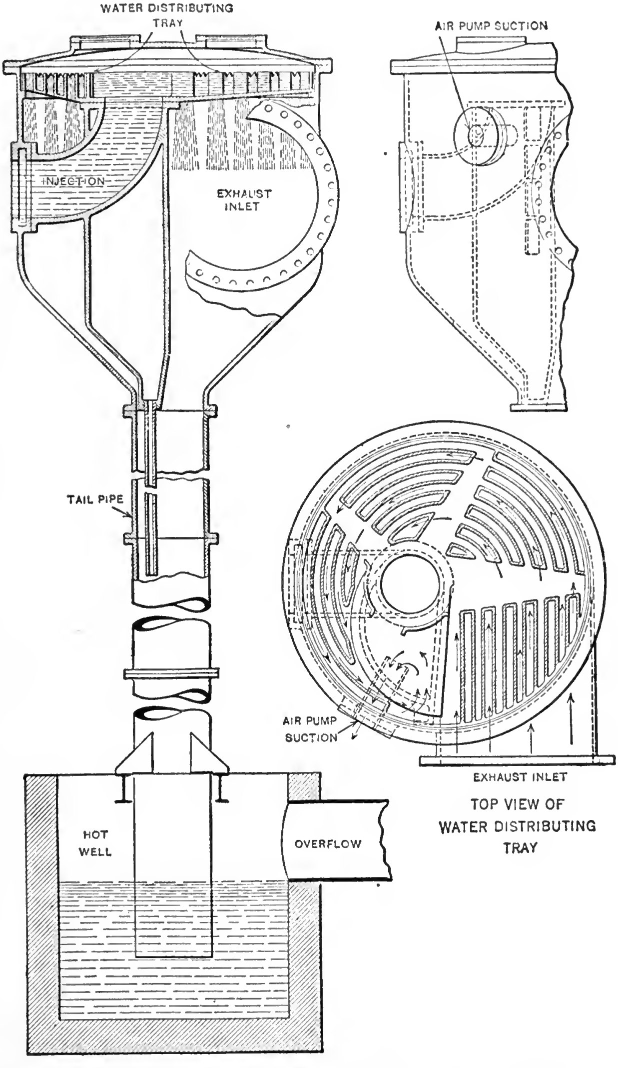


Fig. 138.—Sectional views of a barometric condenser.

a pump for the injection water may be dispensed with, as the vacuum will lift the water to that extent.

Ejector Condensers.—The ejector, eductor, and siphon types of jet condensers depend upon the high momentum of the condensed steam and cooling water to discharge the condensate against atmospheric pressure. No circulating or air pump, or barometric tube is needed. Fig. 139 illustrates two different types of such condensers. Exhaust steam enters the eductor

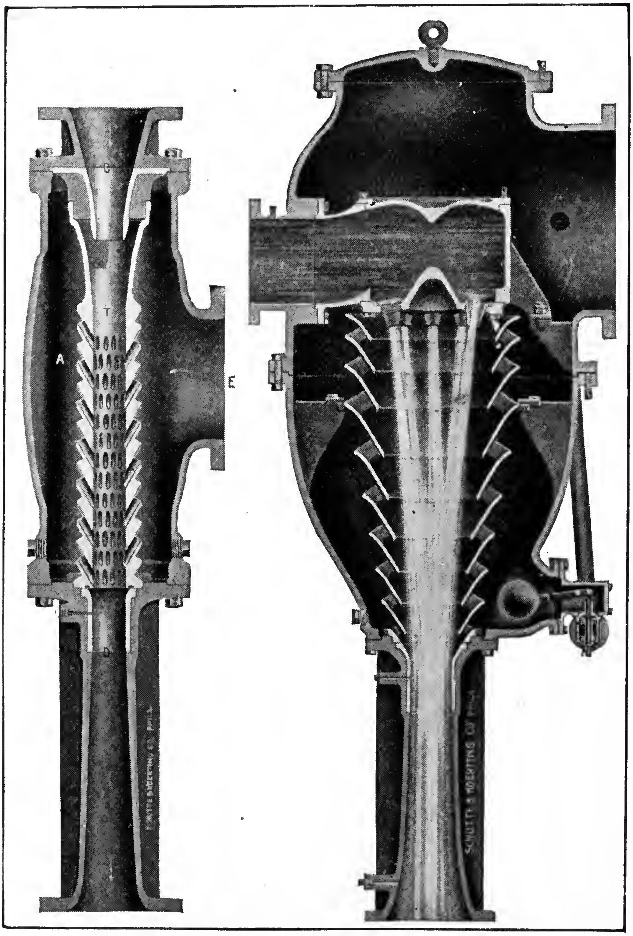


Fig. 139.—Ejector condensers.

condenser at *E*, completely fills the annular chamber *A*, and passes through the small nozzles. The cooling water is continuously drawn in through the nozzle *C* and meets the condensed steam in the tube *T*. Condensation takes place and sufficient velocity is developed to remove the condensed steam, the cooling water, and the air.

Surface Condensers.—A sectional elevation through a surface condenser is shown in Fig. 140. It consists of a cylindrical or rectangular cast iron shell closed at the two ends by suitable heads. Attached to the inner surface of the condenser shell are two tube plates, which are joined by numerous seamless drawn-brass tubes.

Exhaust steam enters the top of the condenser and strikes a baffle plate which protects the upper rows of tubes and distributes the steam to all parts of the condenser. Circulating water enters at the end of the condenser, and passes through the various banks of tubes as shown by the arrows. The steam flows around the tubes and is condensed by coming in contact with the cool surfaces.

In the condenser illustrated, the circulating and wet air pump form the base upon which the condenser rests, although this arrangement is not always adhered to. The pumps (Fig. 140) are connected by a common piston rod which is operated by the central steam cylinder.

Vacuum Pumps

In connection with a condenser installation, a wet-air pump and a circulating pump are required. To maintain a high vacuum, a dry-air pump is used in addition to a hot-well pump and a water circulating pump. The power consumed by the condenser auxiliaries is about 2 per cent. of the total output of the unit the condenser serves. Wet-air pumps are used to remove the condensed steam, the non-condensible vapors, and the cooling water. Dry-air pumps remove only the non-condensible vapors, and are used in steam turbine installations where a high vacuum must be maintained. Hot-well or condensate pumps are those that remove the condensate from surface condensers; circulating pumps force the cooling water through the condenser.

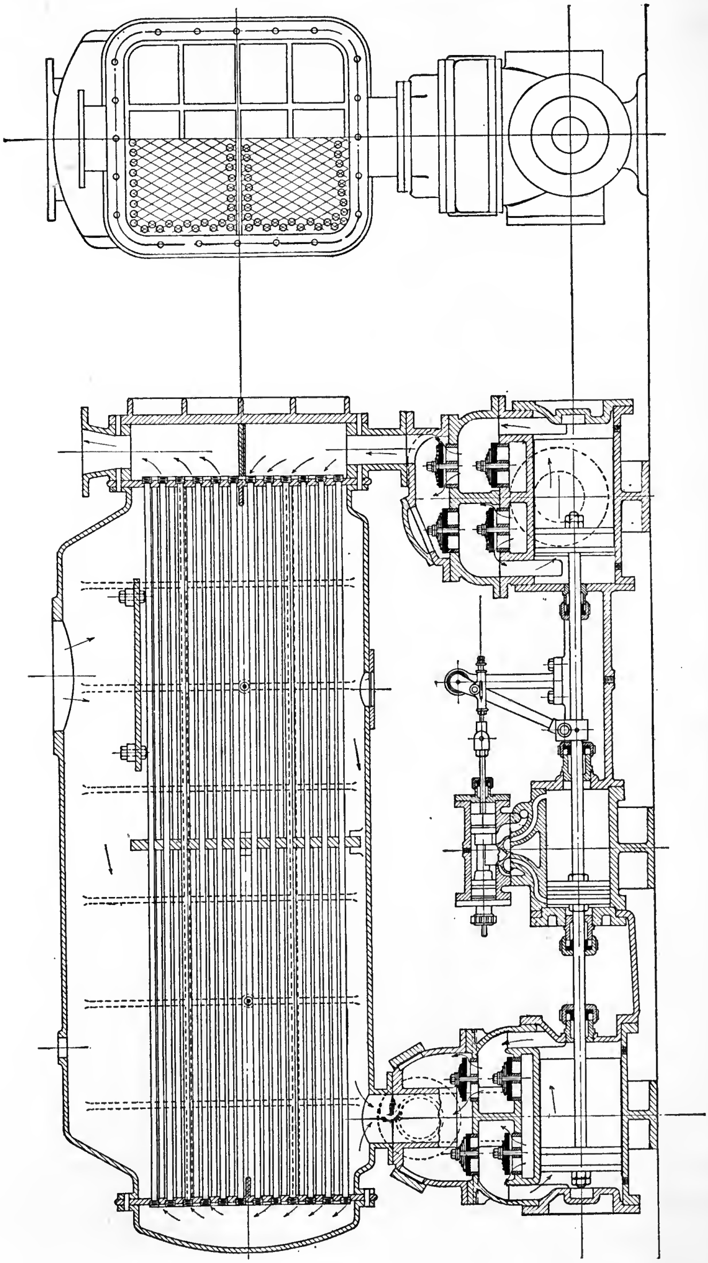


FIG. 140.—Surface condenser.

Wet-air Pumps.—A type of wet-air pump commonly used in connection with jet condensers is illustrated in Fig. 141. These pumps are of the reciprocating type. On the upward stroke of the piston, a lower pressure than that maintained in the condenser is created below the piston, causing the cooling water and condensate, together with the air, to be drawn into the cylinder. The downward stroke of the piston causes the foot valves to close and the entrapped water and air to pass through valves in the piston. When the piston next moves upward the mixture is compressed by the closure of the valves in the piston and is discharged through the valves at the top of the cylinder.

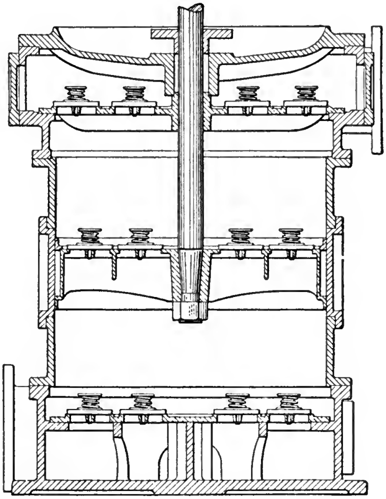


Fig. 141.—Wet-air pump.

Edwards Air Pump.—Fig. 142 illustrates a type of wet-air pump designed for use with surface condensers. Pumps that depend upon foot valves for the entrapping of the air and water in the pump cylinder require an appreciable difference in pressure to insure the opening of the valves. The Edwards air pump, by the elimination of these valves, is capable of maintaining a vacuum from ½ to 1 inch lower than would be possible with pumps of the valve operated type.

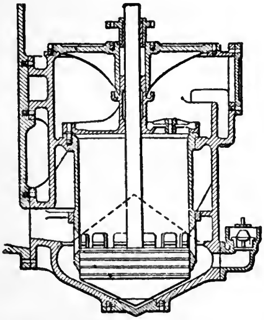


Fig. 142.—Edwards air pump.

The condensed steam flows by gravity from the condenser to the pump, where it collects in the base. Upon the descent of the conical shaped pistons or bucket, the water is projected at high velocity through the ports into the working barrel of the pump, drawing with it considerable air and other non-condensible vapors. On the upward stroke, the ports are closed by the piston, and the water and entrapped air is discharged through the valve at the top of the cylinder.

Dry-air Pumps.—For high vacua, it is more desirable to discharge the air and condensate from the condenser separately. This arrangement necessitates the use of two pumps, a dry-air pump and a wet-air pump.

Fig. 143 illustrates a sectional view of an Alberger dry-air pump. The suction valve is positively actuated by an eccentric on the crank shaft. This valve is provided with an equalizing port, which eliminates the detrimental influence of the air in the clearance space.

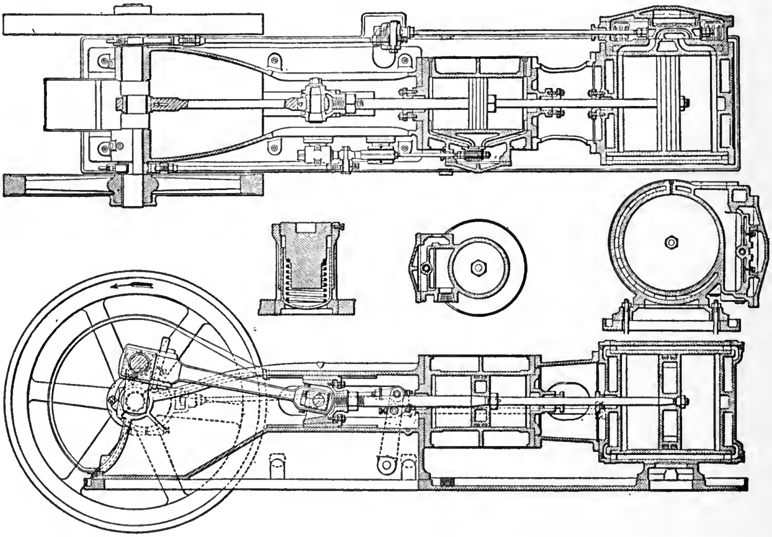


FIG. 143.—Dry-air pump.

When the piston reaches the end of the stroke, the space between it and the cylinder head is filled with air at atmospheric pressure that has not been discharged through the outlet valve. If the piston were to make the return stroke while this air was under pressure, a considerable part of the stroke would be traversed by the piston before this air had expanded to the suction pressure. As a result the drawing in of a fresh charge of air from the condenser would be confined to a small portion of the stroke. To increase the effectiveness of the pump, the valve is moved into its equalizing position before the piston begins its return stroke. The air under pressure is then transferred to the other side of the piston, where it is compressed and is discharged through the valves at the top of the cylinder. By this means the suction side of the piston is effective throughout its entire stroke.

Circulating Pumps.—While reciprocating pumps are used to a very large extent in condenser operation as dry- and as wet-air pumps, centrifugal pumps are generally used as circulating pumps supplying cooling water to surface condensers. Centrifugal pumps are also used as hot-well pumps.

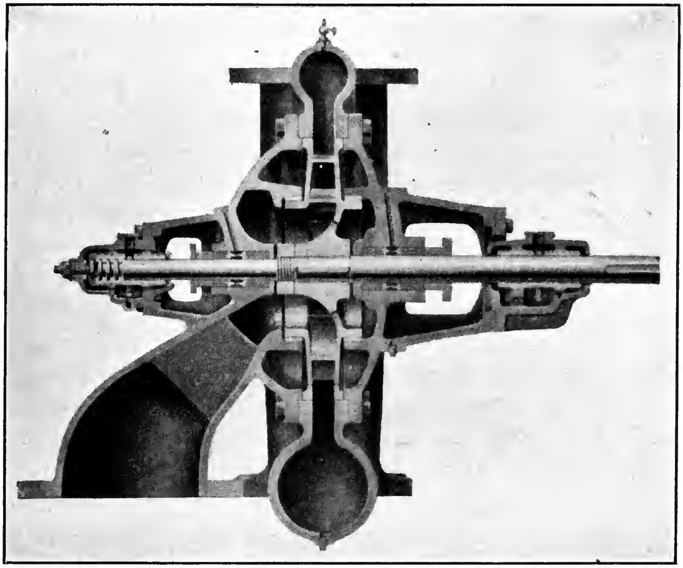


FIG. 144.—Single stage centrifugal pump.

Fig. 144 illustrates a section through a single stage centrifugal pump. It consists of a rotary impeller, into which the water is drawn and, because of the centrifugal force, leaves the tips of the rotor at high velocity. The casing of the pump guides the water from the propeller to the discharge outlet. No valves are required in this type of pump.

The single stage pump is limited in its application to comparatively low heads or pressures. For high heads a greater number of stages are used. In these the water is discharged from one rotor to the next, each rotor acting as a booster. However, condenser operation requires comparatively low heads and the single stage pump will be found sufficient for most installations.

Cooling Ponds and Cooling Towers

Reclaiming Cooling Water.—The quantity of cooling water required to condense steam varies from 30 to 70 pounds for each pound of steam condensed. In many plants this water, after passing through the condenser, is wasted; hence a continuous supply of fresh water is required. In localities where water is plentiful and its cost is low, this practice may be correct, but many plants are handicapped on account of the scarcity or high cost of water. In such cases the saving of cooling water is an important problem. Several methods have been developed to cool the condenser circulating water so that it can be used repeatedly.

The means for reclaiming the water usually adopted at the present time depends upon the cooling effect derived from the evaporation of water. Air has the property of evaporating and absorbing water. The amount of water absorbed depends upon the condition of the air, while the rate of evaporation depends upon the velocity and degree of contact between the air and water. As an illustration, air at a temperature of 90°F. and 50 per cent. humidity, which signifies that the air is only one-half saturated, would be theoretically capable of cooling condenser circulating water to 75°F., or 15° below the temperature of the atmosphere. On the other hand, on a wet rainy day, when the air is saturated with moisture, little or no cooling effect could be produced by evaporation, for the air contains nearly as much water as it will absorb.

The following three systems are used for reclaiming condenser circulating water: cooling ponds, spray ponds, and cooling towers.

When reclaiming circulating water by any of the above methods, an allowance of 2 to 8 per cent. should be made for evaporation.

Cooling Ponds.—Cooling ponds or tanks depend for their cooling effect upon the exposure of a comparatively large area of water to the air. In these the water is cooled partly by radiation but principally by evaporation. The cooling is dependent upon the surface exposed and consequently cooling ponds are usually shallow, but spread over a considerable area. The hot water from the condenser enters the pond at one point, and is cooled by surface evaporation when it reaches the intake point to the condenser.

Cooling ponds are very simple, but are open to the objection that the evaporation is slow. Furthermore they may freeze in winter, and thus cut off the supply of condensing water.

Spray Ponds.—In this system the hot water from the condenser is cooled by spraying it into the air so that it falls in a thin mist into the basin or pond below. The spray brings the air and water into intimate contact, exposes a large amount of water surface to the air, and consequently produces a large cooling effect in a comparatively small space. The water is pumped from the condenser and is forced through the spray nozzles under pressure. Sufficient cooling is effected by the fine spray so that the water may be immediately returned to the condenser.

When compared with the cooling pond, the spray pond occupies less space. A pond depending upon natural evaporation would be approximately 50 times as large as a spray pond for the same cooling capacity. In cases where the cooling effect is not sufficient in a single spraying, the water may be forced through the nozzles a second time, thus securing a double-cooling effect.

Cooling Towers.—A cooling tower consists of a wooden, sheet iron, or concrete chamber that is filled with mats made of steel wire, wooden slats, or tile. Hot water from the condenser is elevated to the top of the tower and is distributed evenly over the top surface. The water in descending is retarded, is broken up by the mats, and is thus brought in intimate contact with the air that ascends through the tower.

The method of supplying the air to cooling towers gives rise to three classifications: open towers or atmospheric coolers; natural-draft towers; forced-draft towers.

The open tower is the simplest, although it requires larger ground space. The mats are supported on a tower of open grill work, so arranged that the descending water will be subjected to the slightest wind. This type of tower has proved successful in localities where the climate is dry and where winds prevail.

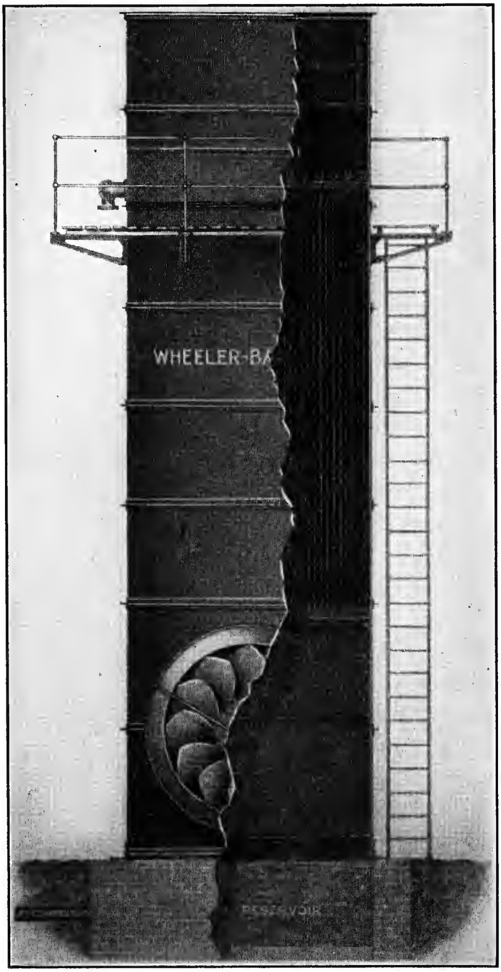


Fig. 145.—Forced-draft cooling tower.

The natural-draft or flue tower depends for its cooling upon the flow of air, which results when the air within the tower and that without are at different densities. The air within the tower will always be the lighter because of its higher temperature and because of the greater amount of moisture it contains. The necessary velocity of air through the tower can be made as desired by proportioning the height of the tower. The natural-draft tower is entirely enclosed, except at top and bottom. The condenser water is distributed at the top, while the air becoming heated is displaced by the colder air which enters at the base of the tower. These towers are suitable for locations where space requirements would prohibit the open or atmospheric tower.

The forced-draft tower lends itself to practically all locations and conditions. Fig. 145 illustrates a sectional view of a forced-draft tower. This type of tower is operated in the same manner as other cooling towers, but a fan is used to create the flow of air through the descending water.

These towers are light and compact, requiring about one-fifth the space occupied by a tower of the natural-draft type. They are entirely independent of the natural circulation of the air, and are consequently more reliable. The power required to operate a forced-draft cooling tower will vary from 2½ to 4 per cent. of the total power generated by the main units.

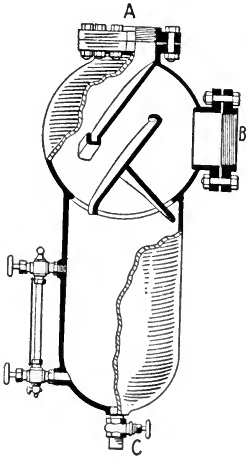


Fig. 146.—Steam separator.

SEPARATORS

Steam Separators.—The function of a steam separator is to protect engines and turbines from the dangerous results that might occur if large quantities of water or grit enter them. When the boiler is improperly proportioned or when it is forced above its rating, there is a possibility of large amounts of water being carried over with the steam. The condensation that occurs in long pipe lines adds to the water in the steam. The steam separator automatically separates the water from the steam, thus protecting the cylinder, and at the same time promotes lubrication by preventing the washing action that results when wet steam is used in the engine cylinder.

Fig. 146 illustrates one type of steam separator. The flow of the steam in passing through the separator is interrupted by corrugated plates. The momentum of the heavier particles of water causes them to be thrown out, and they adhere to the surface of the baffle. The separated water then flows by gravity to the trap or receiver below, from which it is drained.

Separators are made in various sizes, depending upon the size of the pipe to which they are to be attached. They may be used on vertical, horizontal, or angle pipes. Special separators, known as the receiver type, with an extra large water storing capacity are made and are usually installed in plants having long pipe systems, where there is a possibility of large quantities of water suddenly passing through with the steam.

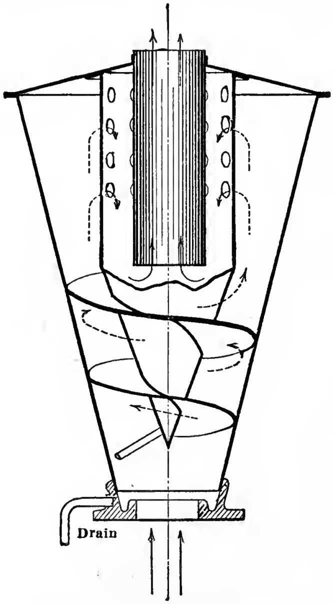


Fig. 147.—Exhaust head.

The separator should be placed as close to the steam chest of the engine as possible. The receiver type of separator is preferable if the engine load is intermittent or fluctuates rapidly.

Exhaust-steam and Oil Separators.—Exhaust-steam separators are constructed on the same principles as steam separators, but their function is to remove oil that may be contained in the exhaust steam. The use of a good oil separator between the engine and the condenser will eliminate the oil from the condensate, thus making it satisfactory as boiler feed water. In the case of surface condensers, oil separators prevent the fouling of the condenser tubes by the oil which would lower the efficiency of the condenser if allowed to accumulate.

In exhaust steam heating the oil separator is used to remove the oil from the steam before it enters the heating system. Oil in the steam would coat the inner surface of radiators with a thin layer of grease which would soon impair the amount of heat transmitted through them.

In the use of feed-water heaters, the oil separator may be entirely independent and separately installed, but in most cases, it is made a part of the heater itself.

In plants where low pressure turbines are utilized, an oil separator is placed between the engine and the turbine. The moisture and oil are thus removed from the exhaust steam before it enters the turbine.

Exhaust Heads.—Fig. 147 illustrates a section through an exhaust head. This device is used to prevent the deposit of any moisture or oil upon roofs and side walks when the exhaust from an engine is allowed to escape to the atmosphere. Exhaust heads are attached in a vertical position at the end of the atmospheric exhaust pipe. Their principle of operation, like that of the separator, depends upon the changing of the course of the steam. The moisture and oil thrown out by centrifugal force collect at the bottom of the head and are drained to waste.

Problems

1. Compare the volumes of steam and of water at atmospheric pressure.

2. Compare the volume of one pound of steam at atmospheric pressure with the volumes at 26 inches vacuum, 28 inches vacuum, and 29 inches vacuum.

3. A condenser gage registers 28.5 inches of mercury. The barometer registers 29.35 inches of mercury. What is the absolute pressure of the air in pounds per square inch? What is the absolute pressure in the condenser in pounds per square inch?

4. Make a sketch of the exhaust piping between an engine and a condenser showing the location of the atmospheric relief valve.

CHAPTER X

STEAM POWER PLANT TESTING

General Rules.—The chief object in the testing of power plant equipment is to secure data from which the cost of operation may be calculated. Tests are also carried on for the purpose of comparing actual with guaranteed results as to capacity and efficiency of the complete power plant or of the separate parts. The effect of different conditions of operation or of changes in design can also be determined by test.

The test of a power plant is essentially a test of each of the various main parts; it is a combined test of the steam boiler, of the steam engine or turbine, and of the other power plant equipment.

The testing of a power plant includes the measurement of certain conditions which are important economically in the operation of the plant. This may be done by the reading of various appliances at specified intervals when the test is in progress or by the use of special instruments of the recording type. The recording instrument gives a continuous record which is often desirable in studying the daily operation of the plant. In reality, with recording instruments, the plant is continuously under test and any variation that may occur from day to day is indicated graphically. The economy test consists, in general, in the measurement of the amount of heat supplied and the amount of energy that has been transformed into useful work.

In testing a boiler, the amount of coal fired would give a direct measure of the heat supplied. To find the amount of energy transformed, the weight of the water evaporated, the quality of the steam generated, the pressure in the boiler, and the temperature of the entering feed water must be measured. To assist in determining the extent of the losses in a boiler plant, such readings as the temperature of the flue gases, the draft at various points in the boiler, and the analysis of the flue gases are usually taken.

The testing of the engine or turbine consists in measuring the weight of the steam supplied together with its quality and pressure at the throttle as well as the pressure of the exhaust; from this data the heat supplied to the motor may be calculated. The delivered power is measured by a Prony brake, an electrical generator, or some other form of dynamometer. As in the case of the boiler, many other readings are taken during the test. These consist of such data as indicator cards, in the case of reciprocating steam engines; the amount of condensing water, and various temperatures at the condenser.

Preparing for the Test.—A thorough examination should be made of the physical condition of all parts of the plant including boilers, furnaces, settings, engine cylinders, piping, valves, etc. Prior to the test any defects that may make the results of the test unfavorable should first be remedied. In boilers, for example, any abnormal leakage found at the tubes, rivets, or metal joints should be repaired. All leakage from blow-offs, drips, etc., or through any steam or water connections which might affect the results should be prevented. In preparing for the test the dimensions of the principal parts of apparatus to be tested should be taken and recorded. Before the test is started it is important that the apparatus to be tested has been in operation a sufficient length of time to attain proper operating conditions.

Starting and Stopping the Test.—In a plant operating continuously day and night the time for starting and stopping the test of a boiler should follow the regular period of cleaning the fires. The fires should be quickly cleaned and then burned low. When this condition has been reached the time should be noted as the starting time, and the thickness of the coal bed, the water level in the boiler, and the steam pressure should be noted. At the close of the test following a regular cleaning, the fires should again be burned low, and when this condition has become the same as that observed at the beginning, the water level and steam pressure also being the same, the time is noted and the test is stopped.

Weighing the Fuel.—The approved method of weighing the fuel burned in a specified interval of time is by the use of ordinary platform scales. If accurate results are to be secured it is not recommended to weigh the fuel in a wheelbarrow or similar conveyance full of coal and assume that all other loads brought into the plant weigh the same; it is also inaccurate to base the weight of the fuel upon the number of strokes of the plunger in certain types of stokers. Even in the use of scales care must be taken to test their reliability by calibrating them with standard weights. In case the use of scales is impracticable, sacks or bags containing a known weight of coal, as measured by a platform scale, may be used to good advantage.

Large plants in which coal handling machinery has been installed use weighing hoppers to measure the coal fed to the boilers. As usually installed the weighing hopper is placed between the main storage bunker in the loft of the plant and the stoker hoppers below. Coal from the main bunker passes first to the weighing hopper. After being weighed the coal is distributed to the stoker hoppers. The weighing hopper travels upon a special overhead track which makes it possible for one weighing hopper to serve several boilers. The scale beams and levers extend downward so that the poise on the weighing beam is read from the boiler room floor.

Weighing the Feed Water.—The most satisfactory method for weighing the feed water, which is the weight of the water evaporated by the boiler, consists in the use of one or more tanks each placed upon platform scales. These are elevated a sufficient distance above the floor to empty into a receiving tank, which is in turn connected to the boiler feed pump. When only one tank is available the receiving tank should be of sufficient size to afford a reserve supply to the pump while the weighing tank is filling.

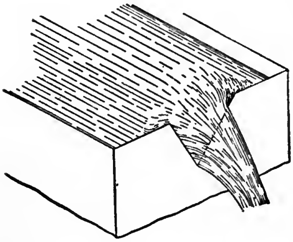


FIG. 148.—Triangular weir.

A great many types of water meters are sold commercially and are often used in measuring the feed water. To insure a fair degree of accuracy the meter should be calibrated before and after the test under the identical conditions it is required to operate.

The measurement of large quantities of hot water is usually accomplished by the use of special types of water meters, weirs, orifices, or automatic water weighers.

Fig. 148 illustrates a weir with a triangular notch, although many other forms of notches may be used. The amount of water discharged is dependent upon the distance or head above the bottom of the weir.

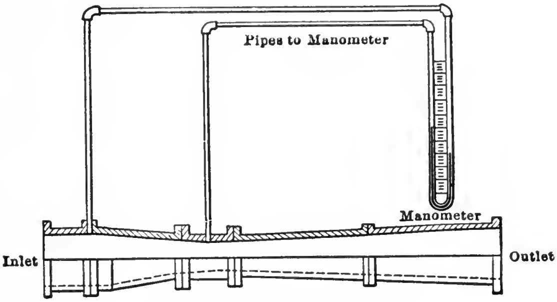


FIG. 149.—Venturi meter.

The Venturi meter is an arrangement of piping in which there is a gradual narrowing of the section followed by a gradual enlargement. Fig. 149 illustrates this type of meter. Tubes entering the meter at the sections shown and attached to the manometer are used in measuring the quantity of water delivered.

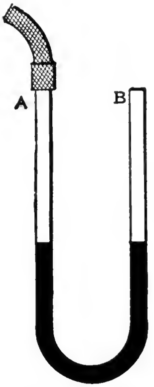


FIG. 150.—U-tube or manometer.

Draft Gages.—The simplest form of draft gage is the U-tube or manometer, illustrated in Fig. 150. For the measurement of draft the tube is filled with water and is connected at "A" by means of tubing to the point where the pressure is to be measured. The amount of pressure will be indicated by the difference in the level of the liquid and may be measured in inches of water.

For the measurement of slight pressures an inclined tube, as illustrated in Fig. 151, may be used. The bottle *B* to which the inclined tube *CD* is attached is filled with water. The outer end of the inclined tube is attached to the chamber in which the pressure is to be measured. The pressure is measured as with the U-tube (Fig. 150), but by the use of the inclined tube the movement of one inch in a vertical scale is magnified.

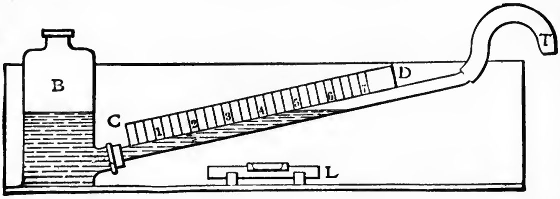


Fig. 151.—Inclined tube manometer.

Temperature Measurement.—Temperatures are usually measured by means of one of the following types of thermometers: mercurial thermometers; electrical resistance thermometers; mechanical pyrometers; thermoelectric pyrometers.

The ordinary mercury in glass thermometer is commonly used for temperatures less than 500°F.; above 500° special nitrogen filled glass thermometers must be used.

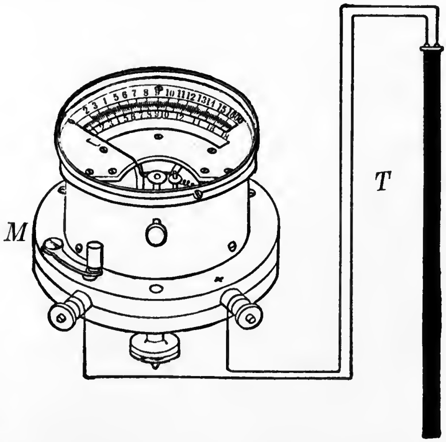


Fig. 152.—Diagram of the thermoelectric method of temperature measurement.

Electrical resistance thermometers are based upon the principle that the resistance of certain metals changes with change of temperature. The thermometer element is constructed of some metal, like platinum, and the variation of resistance measured by a Wheatstone bridge.

Mechanical pyrometers consist of two metal-rods whose rate of expansion differ. The rods are connected through gears and levers to a pointer which rotates over the dial graduated in degrees of temperature.

Thermoelectric pyrometers are based upon the principle that an electromotive force is produced when two wires of different metals are joined and heated. Fig. 152 illustrates a thermoelectric pyrometer. *T* is a porcelain tube which holds the two dissimilar metal wires and which is placed at the point where the temperature is to be read. *M* is a meter for measuring the impressed voltage; it is provided with a scale calibrated in degrees.

Measuring the Weight of Steam.—The most satisfactory method of weighing the amount of steam consumed by the engines or turbines is by the use of platform scales and surface condensers. This method utilizes two scales and two tanks which are alternately filled with condensed steam from the condenser, weighed, and emptied.

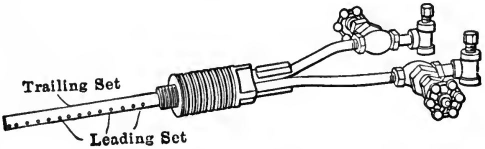


FIG. 153.—Steam flow meter nozzle.

Various forms of steam meters may be employed for measuring the steam, provided such meters are properly calibrated under the conditions to which they will be subjected when in use.

Figs. 153 and 154 illustrate one type of steam meter. This instrument measures the steam flow by recording the velocity. The nozzle plug (Fig. 153) is inserted into the steam pipe, and in this plug are two sets of holes which communicate through separate pipes to the meter (Fig. 154). The leading set of holes is subjected to the velocity and the pressure of the steam while the trailing set is subjected only to the pressure. Their difference records the effect caused by velocity.

The recording meter is essentially a mercury U-tube or manometer. A difference of pressure in the nozzle plug causes a difference in height of the mercury. Change in the position of

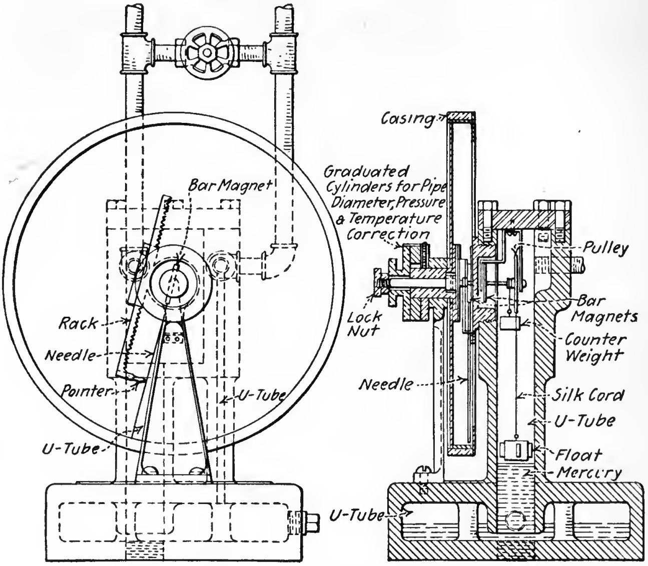


FIG. 154.—Steam flow-meter.

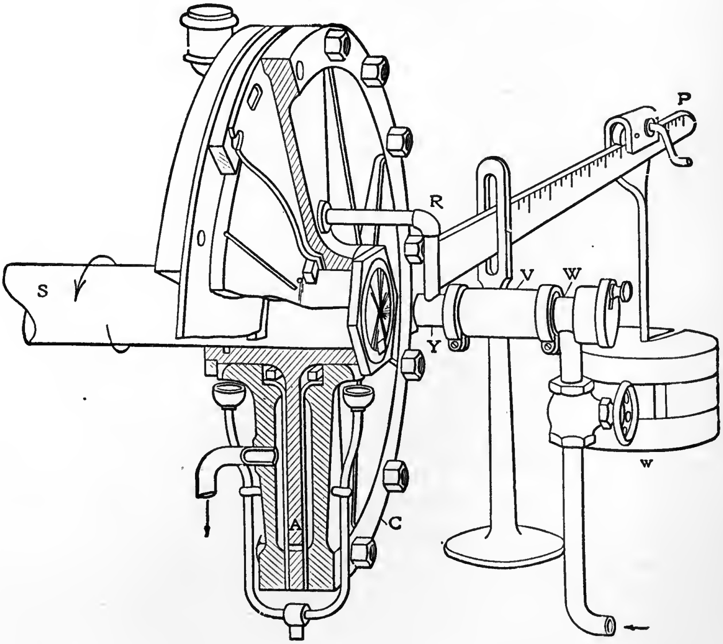


FIG. 155.—The Alden water brake.

the mercury column is measured by a small float suspended from pulleys which in turn move the indicating needle.

Measurement of Power.—One of the simplest means of measuring the power delivered by a small motor is by the application of a Prony Brake to the rim of the wheel as explained in Chapter VII. For motors of large capacity or operating at high speeds some other type of dynamometer or an electrical generator must be used.

Another type of brake for absorbing and measuring power is some form of water friction brake. Fig. 155 illustrates one type of water brake. It consists of a disk *A* which is connected to the shaft *S* transmitting the power. The disk revolves in a copper chamber filled with oil while cooling is effected by the circulation of water around the outer surface of the copper chamber. The friction of the oil producing the braking effect is transmitted to the arm *P* where it is measured as in the Prony brake.

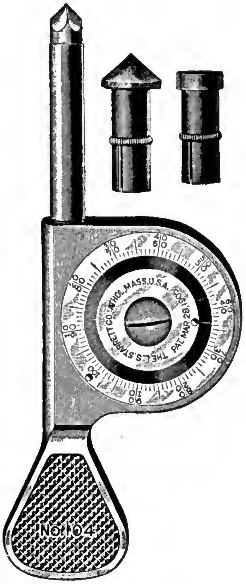


Fig. 156.—Speed counter.

Measurement of Speed.—For determining the speed of an engine shaft in revolutions per minute a speed indicator Fig. 156 and watch, or a tachometer Fig. 157 is used. The tachometer is more convenient, as it indicates on the dial the revolutions per minute.

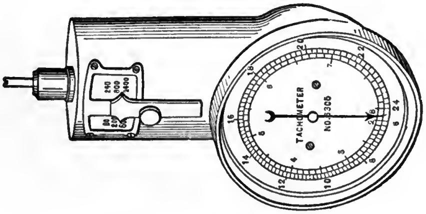


Fig. 157.—Tachometer.

Indicator and Calorimeters.—Steam engine indicators, steam calorimeters, coal calorimeters, and other important instruments used in power plant testing were explained in previous chapters.

A. S. M. E. Code.—Complete and more detailed instructions concerning the testing of steam power plants and power plant equipment will be found in the *Rules for Conducting Performance Tests of Power Plant Apparatus,* published by the American Society of Mechanical Engineers.

Problems

1. Examine some water meter and explain, using clear sketches, how the meter works.

2. Explain the principles upon which the construction of recording instruments are built.

3. From the A. S. M. E. Power Plant Code compile a table showing the principal data to be taken of a test on a non-condensing steam power plant.

CHAPTER XI

INTERNAL COMBUSTION ENGINES

The internal combustion engine, commonly called a gas engine, differs from the steam engine, which is an external combustion motor, in that the transformation of the heat energy of the fuel into work takes place within the engine cylinder.

History.—The earliest internal combustion engine was the gunpowder engine invented by Huyghens in 1680. In the Huyghens engine a charge of gunpowder was introduced into a vertical cylinder filled with air and exploded; the products of combustion were driven out of the cylinder through valves, and the piston, which was at the end of the stroke, was forced down by the atmospheric pressure into the vacuum thus formed.

The first attempt to produce power from an inflammable gas, manufactured by the distillation of coal or oil, was made by Barber in 1791. The Barber motor included an air pump and a compressor which forced the inflammable gas and air into a vessel, where the mixture was ignited; the burning mixture issuing from the vessel impinged against the vanes of a paddle wheel and produced the rotation of a shaft connected to the machinery to be driven. The first reciprocating engine using an inflammable gas was invented by Street in 1794.

Lebon in 1801 first suggested the compression of the mixture of gas and air before ignition. This was applied by Barnet in 1838.

From 1801 to 1860 many efforts were made to produce a practical internal combustion engine. Several types of free piston engines were developed during this period in which the explosion of a mixture of gas and air was utilized in moving upward in a vertical cylinder a piston which was free from the connecting rod. The work was done on the return stroke by the pressure of the atmosphere forcing the piston down, the piston rod on its downward stroke producing rotary motion through a rack meshing with a spur pinion and connected by a ratchet and pawl to the driving shaft.

The Lenoir engine, which was invented about 1860, was the first internal combustion engine to be used commercially to any extent for producing power. The Lenoir engine was a horizontal double-acting reciprocating motor. The mixture of the fuel and air was drawn into one end of the engine cylinder during the first part of the stroke, the inlet valve being closed at about one-half of the stroke, when the mixture was ignited. The explosion (rapid combustion) of the mixture forced the piston to the end of the stroke. Near the end of the stroke the exhaust valve opened, and the products of combustion were expelled during the return stroke. The same operation took place at both ends of the cylinder, the energy stored in the flywheel driving the piston forward during the suction part of its stroke. The Lenoir engine, similar to the steam engine, had two working strokes during each revolution, but was superseded by engines working on the Otto or Diesel cycles, which have only one working stroke for every two revolutions of the crank shaft.

The Otto Internal Combustion Engine Cycle.—The majority of modern commercial internal combustion engines operate upon the Otto internal combustion engine cycle, which was suggested by Beau de Rochas in 1862, and which was made a practical success by Nicholas A. Otto in 1878. The term engine cycle is applied to the series of events which are essential for carrying out the transformation of heat into work. The Otto internal combustion engine cycle requires four strokes of the piston and comprises five events, which are: suction, compression, ignition, expansion, and exhaust.

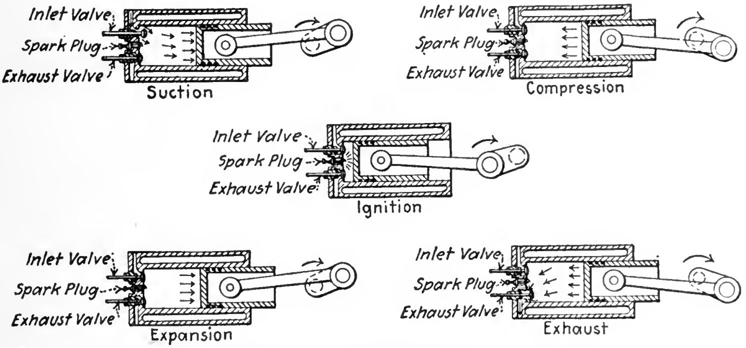
The action of an internal combustion engine working on the four-stroke Otto cycle is illustrated in Figs. 158 to 162.

1. Suction of the mixture of air and gas through the inlet valve takes place during the complete outward stroke of the piston, the exhaust valve being closed. This stroke of the piston is called the suction stroke and is illustrated in Fig. 158.

2. On the return of the piston, shown in Fig. 159, both the inlet and exhaust valves remain closed and the mixture is compressed between the piston and the closed end of the cylinder. This is called the compression stroke. Just before the compression

stroke of the piston is completed, the compressed mixture is ignited by a spark (Fig. 160) and rapid combustion or explosion takes place.

3. The increased pressure within the cylinder due to the rapid combustion of the mixture drives the piston on its second forward stroke, which is the power stroke (Fig. 161). This power stroke, or working stroke, is the only stroke in the cycle during which power is generated. Both valves remain closed until the end of the power stroke, when the exhaust valve opens and provides communication between the cylinder and the atmosphere.



FIGS. 158–162.—The events in the Otto Cycle.

4. The exhaust valve remains open during the fourth stroke called the exhaust stroke, Fig. 162, during which the burned gases are driven out from the cylinder by the return of the piston.

The simplest type of internal combustion engine operating on the Otto four-stroke cycle is the gasoline engine which is illustrated in Fig. 163. The fuel from the liquid fuel tank *T* is supplied to the mixing valve or carburetor through the fuel regulating valve *G*. The air, through the air pipe *A*, enters the same carburetor and is thoroughly mixed with the fuel. The mixture of air and vaporized fuel enters the engine cylinder *C* through the inlet valve *V* as the piston *P* moves on the suction stroke. The mixture is then compressed, and ignited by an electric spark produced at the spark plug *Z*, by current furnished from the battery *B*. The ignition of the mixture is followed by the power stroke. The reciprocating motion of the piston *P* is communicated, through the connecting rod *R* to the crank *N*, and is changed into rotary motion at the crank shaft *S*. The crankshaft *S*, while driving the machinery to which it is connected, also turns the valve gear shaft, sometimes called the two-to-one shaft, through the gears *X* and *Y*. The gear *Y* turns once for every two revolutions of the crank, and near the end of the power stroke opens the exhaust valve *E* through the rod *D* pivoted at *O*.

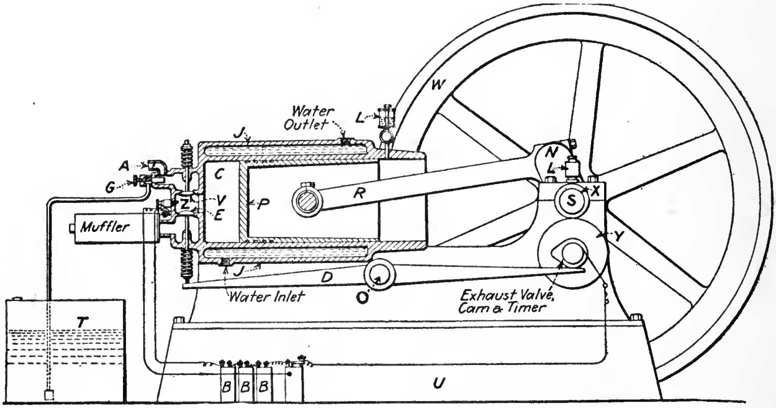


FIG. 163.—Parts of a gasoline engine.

In larger engines the valve gear shaft also opens and closes the admission valve *V* and operates the fuel pump and ignition system. As the temperatures resulting from the ignition of the explosive mixture is usually over 2000°F., some method of cooling the walls of the cylinder must be used in order to facilitate lubrication, to prevent the moving parts from being twisted out of shape, and to avoid the ignition of the explosive mixture at the wrong time of the cycle. One method of cooling gas engines is to jacket the cylinder *J*, that is, to construct a double-walled cylinder and circulate water between the two walls, through the jacket space. The base *U* supports the various parts of the engine; the flywheel *W* carries the engine through the idle strokes. Besides the above details, every gas engine is usually provided with lubricators *L* for the cylinder and bearings, and with a governor for keeping the speed constant at variable loads.

An indicator diagram, taken from a four-stroke cycle internal combustion engine, using gasoline as fuel, is illustrated in Fig. 164. *IB* is the suction stroke, *BC* the compression stroke, *CD* shows the ignition event, *DE* the power stroke, and *EI* is the exhaust stroke. The direction of motion of the piston during every stroke is illustrated in each case by arrows. Lines *AF* and *AG* were added to the indicator diagram; *AF* is the atmospheric line, while *AG* is the line of pressures. From Fig. 164 it will be noticed that part of the suction stroke occurs at a pressure lower than atmospheric. The reason for this is that a slight vacuum is created in the cylinder by the piston moving away from the cylinder head. The vacuum helps to draw the mixture of fuel and air into the cylinder.

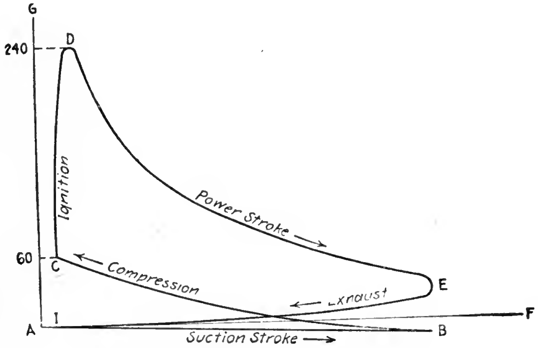


FIG. 164.—Gas-engine indicator card.

Modern internal combustion engines, operating on the Otto four-stroke cycle, will convert 14 to 30 per cent. of the heat available in the fuel into work. The Lenoir engines, in which the mixture was not compressed previous to ignition, converted only about four per cent. of the heat available in the fuel into work.

The efficiency of engines operating on the Otto cycle depends upon the pressure to which the mixture of fuel and air is compressed before ignition. Theoretically, the greater the compression pressure, the better is the economy. Practical considerations and the danger of preignition limit the compression pressures for various fuels to the following values in pounds per square inch: Gasoline 60 to 90 pounds, kerosene 50 to 80 pounds, alcohol 120 to 180 pounds, natural gas 80 to 120 pounds, producer gas 120 to 160 pounds, blast furnace gas 120 to 190 pounds.

From the above values of practical compression pressures it is evident that with fuels high in hydrocarbons lower compression pressures should be employed than with fuels which are low in these constituents.

The Two-stroke Cycle Engine.—The internal combustion engine working on the four-stroke cycle requires two complete revolutions of the crankshaft, or four strokes of the piston to produce one power stroke. The other three are only idle strokes, but power is required to move the piston through these strokes, and this has to be furnished by storing extra momentum in heavy flywheels. The Otto cycle can be modified so that the five events can be carried out during only two strokes of the piston by precompressing the mixture of fuel and air in a separate chamber, and by having the events of expansion, exhaust, and admission occur during the same stroke of the piston. In large two-stroke cycle engines the air and fuel for the mixture are compressed and delivered separately by auxiliary pumps driven from the main engine shaft. The precompression of the mixture in the case of small two-stroke cycle engines is accomplished by having a tightly closed crank case, or by closing the crank end of the cylinder and by providing a stuffing box for the piston rod.

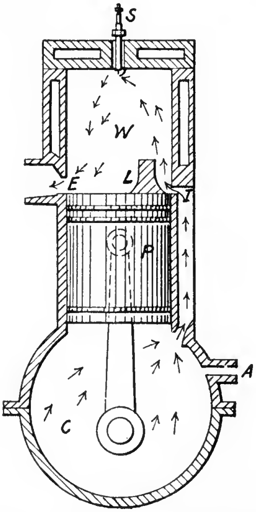


Fig. 165.—Small two-stroke cycle engine.

The main features of the two-stroke cycle internal combustion engine are illustrated in Fig. 165. On the upward stroke of the piston *P*, a partial vacuum is created in the crank case *C*, and the explosive mixture of fuel and air is drawn in through a valve at *A*. At the same time a mixture previously taken into the upper end of the cylinder *W* is compressed. Near the end of the compression stroke, the mixture is fired from a spark produced at the spark plug *S*. The explosion of the mixture drives the piston on its downward or working stroke. The piston descending compresses the mixture in the crank case to about 6 or 8 pounds above atmospheric, the admission valve at *A* being closed as soon as the pressure in the crank case exceeds atmospheric. When the piston is very near the end of its downward stroke, it uncovers the exhaust port at *E* and allows the burned gases to escape into the atmosphere. The piston continuing on its downward stroke next uncovers the port at *I*, allowing the slightly compressed mixture in the crank case *C* to rush into the working part of the cylinder *W*. Thus two full strokes of the piston complete one cycle.

The distinctive feature of the two-stroke cycle engine is the absence of valves. The transfer port *I* from the crank case *C* to the working part of the cylinder *W*, as well as the exhaust port *E*, are opened and closed by the piston.

Large two-stroke cycle engines are often made double-acting and have the same number of power impulses per revolution as the single-cylinder steam engine. The proper amounts of gas and air are delivered to each end of the piston at the correct time by auxiliary pumps. An admission valve is provided at each end of the cylinder. The exhaust takes place through ports near the middle of the cylinder, which are uncovered by the piston at the end of each working stroke.

To offset the advantages resulting from fewer valves, less weight, and greater frequency in working strokes, the two-stroke cycle engine is usually less economical in fuel consumption and is not as reliable as is the four-stroke cycle engine. As the inlet port *I* (Fig. 165) is opened while the exhaust of the gases takes place at *E*, there is always some chance that part of the fresh mixture will pass out through the exhaust port. Closing the exhaust port too soon will cause a decrease in power and efficiency, on account of the mixing of the inert burned gases with the fresh mixture. By carefully proportioning the size and location of the ports, and by providing the piston with a lip at *L* (Fig. 165) to direct the incoming mixture toward the cylinder head, the above losses may be decreased. In large two-stroke cycle engines an effort is made to eliminate the above loss by forcing a current of air through the cylinder by the air pump, while the exhaust port remains open. In any case the scavenging of the cylinder of the waste gases is not as thorough in the two-stroke cycle as in the four-stroke cycle engine, where one complete stroke of the piston is allowed for the removal of the exhaust gases. The four-stroke cycle engine has also the advantage of wider use and longer period of development.

The Diesel Internal Combustion Engine Cycle.—The Diesel engine cycle is applied only to oil engines. This cycle, similar to the Otto, comprises five events: suction, compression, ignition, expansion, and exhaust. In the Otto internal combustion engine cycle, air is mixed with the fuel in definite proportions and the combustible mixture is subjected to the process of compression. In the Diesel engine cycle only air is admitted to the cylinder during the suction stroke, so that compression pressures as high as desired are permitted without the danger from pre-ignition. The compression pressures used with Diesel engines vary from 450 to 500 pounds per square inch. The higher compression pressure limit in this case is not dependent upon the composition of the mixture within the cylinder but upon construction details. At the end of the compression stroke of the Diesel engine piston, oil fuel is injected into the cylinder. The oil enters the cylinder in the form of a fine spray, mixes with the highly compressed air, which is at a temperature of about 1000°F., is ignited and burns at nearly constant pressure. The duration of the oil injection is governed by the load upon the engine. This period of oil injection, as well as the compression pressure, influences the fuel economy of a Diesel engine.

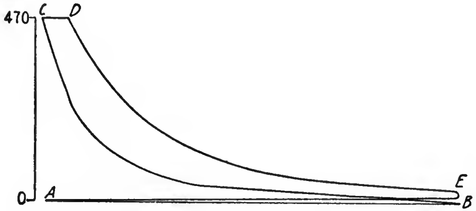


FIG. 166.—Indicator card from Diesel oil engine.

An indicator diagram taken from a Diesel oil engine is shown in Fig. 166. Air is drawn into the cylinder during the suction stroke *AB*. The return of the piston compresses the air to a pressure of about 470 pounds per square inch during the stroke

BC. The fuel-oil is then gradually introduced by means of an oil pump, to an amount depending upon the load, and burns during *CD*, the first part of the third stroke. This is followed by the expansion of the gases within the cylinder to the end

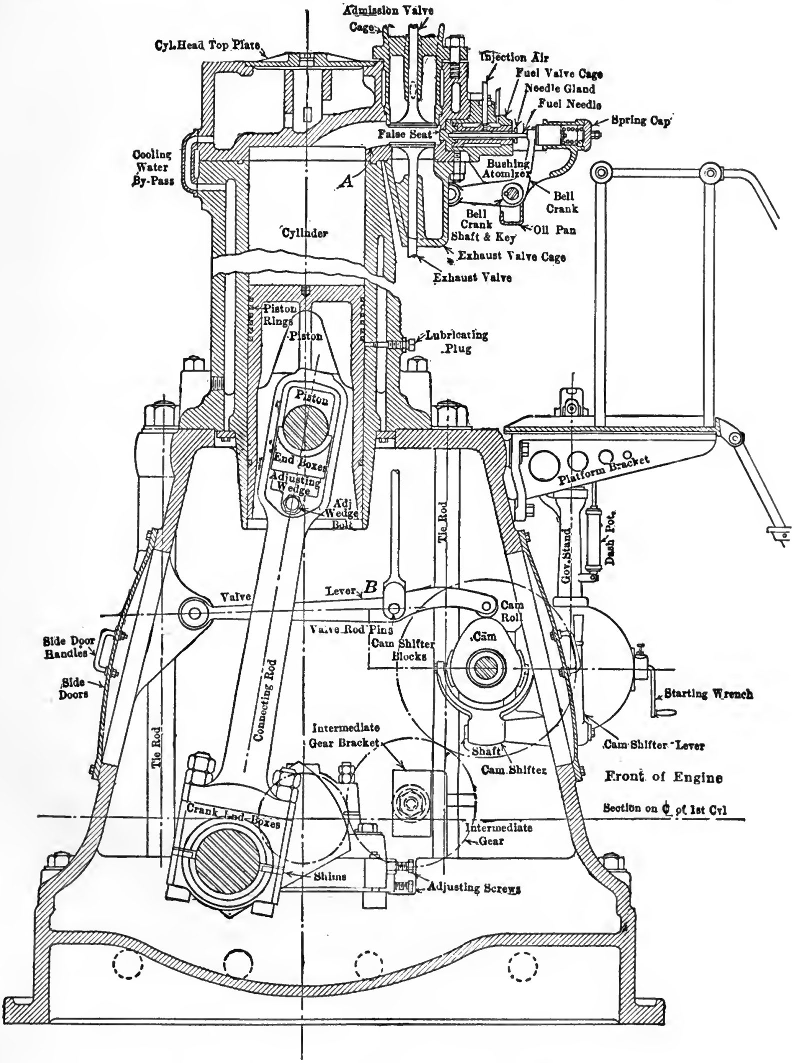


FIG. 167.—Cross-section of American Diesel engine.

of the third stroke along DE. At E the exhaust valve opens and the burned gases are exhausted from the cylinder during the fourth stroke EA.

A section through a Diesel engine is illustrated in Fig. 167. Internal combustion engines operating on the Diesel cycle are more expensive to build and require better supervision than engines operating on the Otto cycle, but give better fuel economy and are capable of operating with the very cheapest liquid fuels. Under good conditions Diesel engines will convert more than 30 per cent. of the heat in the fuel into work, while oil engines operating on the Otto cycle will usually convert only about 20 per cent.

Details of Internal Combustion Engines.—The fundamental details of an internal combuston engine are:

1. *The Fuel System.*—This includes fuel storage, piping from the storage to the engine, and a device for preparing the mixture of air and fuel. In order to form an explosive mixture, air must be mixed in certain definite proportions with the fuel, and this can be accomplished only when the fuel is in the gaseous state, or is a mist of liquid fuel easily vaporized at ordinary temperatures. Thus the essential difference between internal combustion engines using the various fuels is in the construction of the device for preparing the fuel before it enters the engine cylinder. If the fuel is initially a gas, only a mixing valve is necessary to control the proportions of fuel and air. Fuels which are in the liquid state must be vaporized and mixed with air to form an explosive charge. The devices required for preparing liquid fuels depend on the character of the fuel, a heavy fuel requiring heat, while a volatile fuel, such as gasoline, is easily vaporized at ordinary temperatures by being broken up into fine mist. When an engine uses a volatile liquid fuel, like gasoline, the fuel is vaporized and mixed with the correct proportion of air in a device called a carburetor. Various types of carburetors will be illustrated and explained in Chapter XIII.

2. *A Jacketed Cylinder and Piston.*—In small engines only the cylinder and cylinder head must be cooled. In large engines it becomes necessary to cool also the piston and the exhaust valve to prevent overheating of the metal. The methods used in cooling gas engine cylinders are illustrated in Figs. 168 and 169.

An air-cooled cylinder is illustrated in Fig. 168. This cylinder is cast with webs, and air is circulated by means of a fan driven by the engine. The air cooling system has not been found practical for stationary engines above 5 horsepower, as there is no positive temperature control with this system. This lack of temperature control results in the decomposition of the cylinder oil and in carbon deposits on the piston and cylinder walls. Considerable success has been attained with air cooled motors for automobiles and motorcycles.

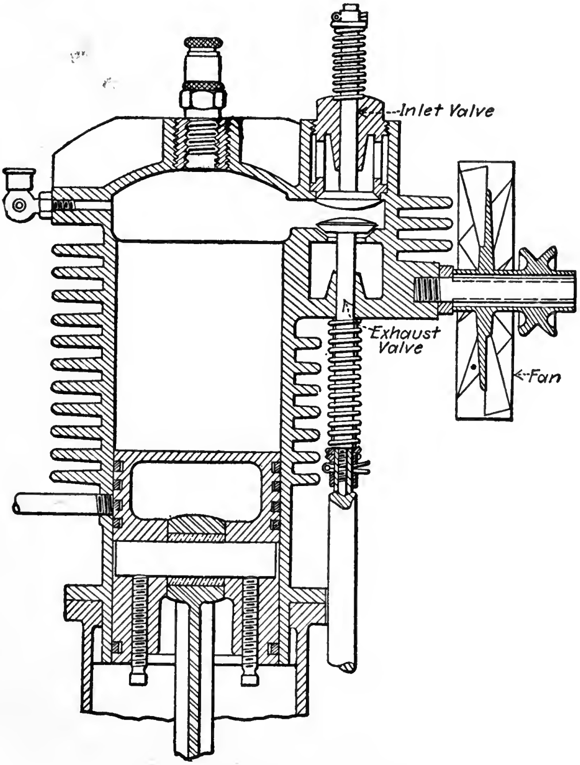


FIG. 168.—Air-cooled cylinder.

The cooling of engine cylinder walls by means of water is the most common method. In this case the cylinder barrel or the cylinder barrel and cylinder head are jacketed; that is, they are built with double walls and water is circulated through the space between the walls. The cylinder wall or barrel is cast separate from the jacket, except in small engines, where the cylinder barrel and jacket walls are cast together. In order to definitely control the temperature of the water jacket, the forced system of water circulation (Fig. 169) is generally used for stationary engines.

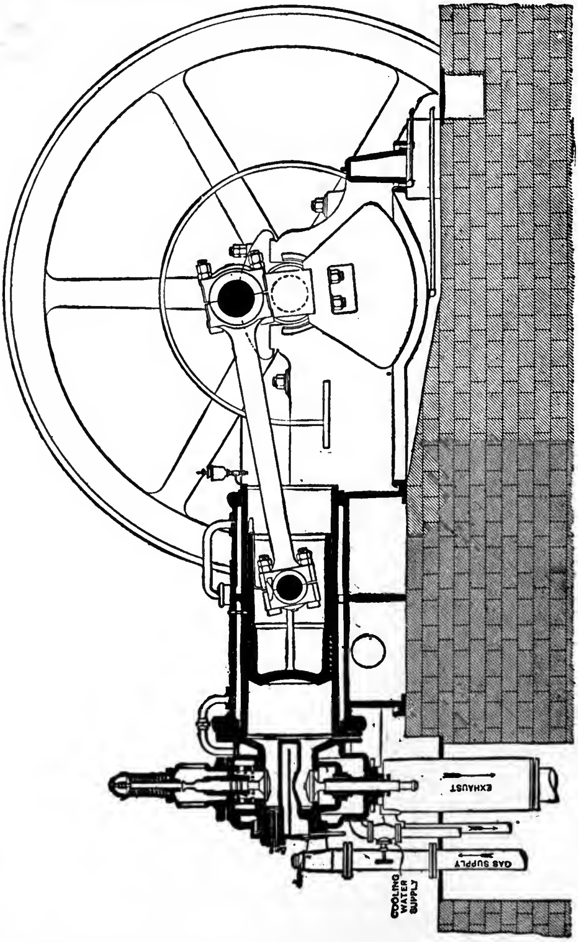


Fig. 169.—Water-cooled gas engine.

Cylinders for internal combustion engines are single acting and are usually fastened to the frame at one end only, to allow for the free expansion of the metal.

The trunk type of piston (Fig. 169) is most commonly used, for it acts not only as a piston but also as a cross-head. The piston is usually provided with three or more rings, as it is very important that leakage past the piston be eliminated.

3. *Inlet and Exhaust Valves.*—With the exception of some automobile motors, which are equipped with sleeve valves, valves for internal combustion engines are generally of the poppet or mushroom type, with conical seats (Fig. 169).

The inlet valves are not jacketed, as they are cooled by the incoming mixture during the suction stroke. Exhaust valves must be cooled in all except very small engines, as these valves are in contact with very hot gases for a considerable period of time.

Small engines are sometimes provided with inlet valves which are automatically operated by the suction of the piston, being held to their seats by weak springs. Automatically operated valves are uncertain in their action and are seldom used. Mechanically operated valves are positively controlled and are generally used both for inlet and for exhaust valves.

The valves are operated by means of cams or eccentrics from an auxiliary shaft which is driven by means of gears from the main engine shaft. In the four-stroke cycle engine the auxiliary shaft is operated at one-half the speed of the main shaft. In small engines the valves are actuated by cams, but in large engines eccentrics are employed for this purpose.

4. A mechanism for changing the reciprocating motion of the piston into rotation at the crank shaft. This change is accomplished by means of a connecting rod and crank.

5. *Ignition System.*—Ignition of the mixture in modern internal combustion engines is accomplished either by a spark, or automatically by the high compression to which either the air or the mixture is subjected in the engine cylinder. The subject of ignition will be treated in detail in Chapter XIII.

6. A governor for keeping the speed constant as the power developed by the engine varies. The governing mechanism is operated by the speed variations of the engine and the speed control is accomplished either by the hit-or-miss, or by the throttling methods as will be explained later.

7. A flywheel for carrying the engine through the idle strokes.

8. Engine frame and bearings for supporting the various parts of the engine.

9. Foundations for the engine and auxiliaries.

10. Lubricating system which includes grease cups, sight-feed oilers, and positive force feed oilers. For high speed motors the forced-flooded system of lubrication is commonly employed. In this system a pump forces oil to the various bearings, keeping them flooded with oil at all times.

Oil Engines.—The first successful oil engines were gasoline engines, as gasoline is the lightest of all commercial hydrocarbons and is easily vaporized at ordinary atmospheric temperatures. Gasoline engines consume one-eighth to one-tenth of a gallon of gasoline per brake horsepower per hour. Gasoline is the most important fuel for small stationary and portable engines; also for light-weight high speed engines, such as are used on automobiles and aeroplanes.

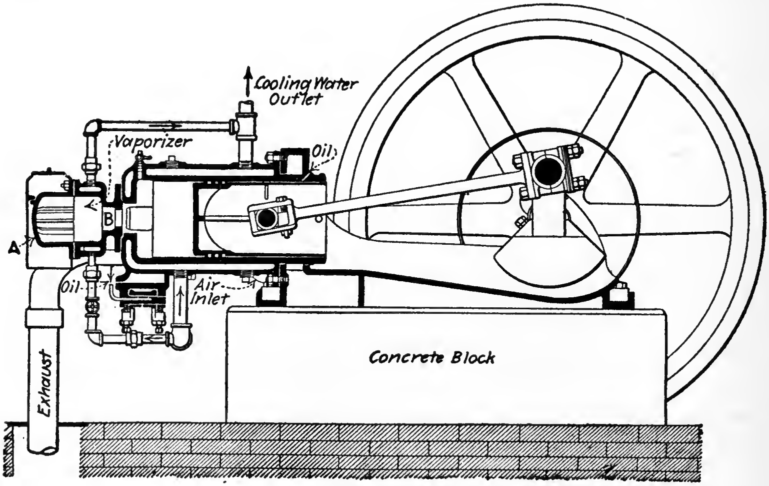


Fig. 170.—Hot-bulb oil engine.

The ordinary gasoline engines (Fig. 163) which employ electric ignition cannot operate satisfactorily on heavy petroleum fuels. The type of hot bulb engine, illustrated in Fig. 170, has been found satisfactory for petroleum oils as heavy as 30° Baumé (see Table 7, Chapter XII). This engine is provided with an unjacketed vaporizer *A*, which communicates with the cylinder by means of the small opening *B*. The vaporizer is raised to a red heat before starting, by means of a torch, and is kept hot by repeated explosions when the engine is running. This engine works on the regular four-stroke Otto gas-engine cycle. During the suction stroke of the piston only air is sucked into the cylinder and the charge of oil fuel is injected into the vaporizer by a pump. On the return stroke the air is compressed, forced into the vaporizer, mixed with the fuel and automatically ignited. This is followed by the expansion and exhaust strokes, as in other internal combustion engines.

A modification of this type of engine is the so-called semi-Diesel type of oil engine, which can be operated on the lowest grades of petroleum fuels. One type of semi-Diesel engine is illustrated in Fig. 171. Like the Diesel, the semi-Diesel engine compresses only air, but operates at a compression pressure of about 300 pounds per square inch, depending partly on a hot unjacketed combustion chamber to ignite the charge. During the suction stroke a charge of air is drawn into the cylinder, which is compressed into the combustion space. At or near the end of the compression stroke, the fuel oil is admitted in a fine spray, is mixed with the air and is ignited. The resulting expansion forces the piston on its working stroke. Near the end of the working stroke, the exhaust valve is opened and the piston on its

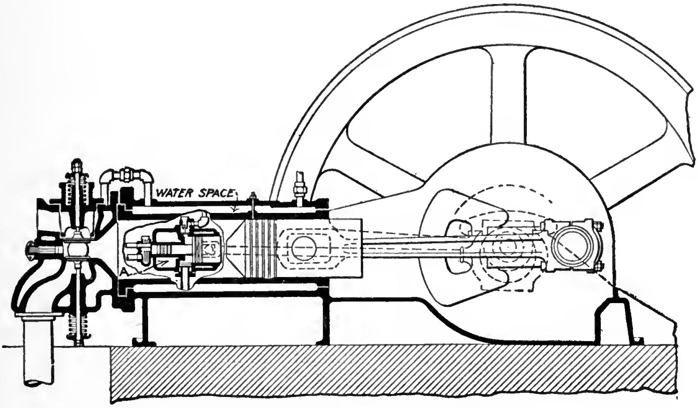


Fig. 171.—Semi-Diesel oil engine.

return stroke expels the burnt charge. An indicator card from a semi-Diesel oil engine is illustrated in Fig. 172.

The Diesel engine, previously described, is the most economical type of engine for low grades of fuel. While its high cost limits its field of application in small sizes, this is compensated in sizes of 100 horsepower and greater by the higher fuel economy and by the ability of this type to operate on any liquid fuel without leaving an appreciable residue. Recent tests indicate that Diesel engines will consume only about 0.45 pound of low grade oil per brake horsepower per hour.

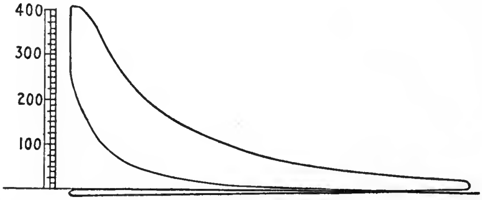


Fig. 172.—Indicator card from a semi-Diesel oil engine.

Losses in Internal Combustion Engines.—Internal combustion engines convert 10 to 30 per cent. of the heat energy supplied by the fuel into useful mechanical work. The two greatest losses are those due to the heat carried away by the jacket water and by the exhaust gases. The loss in the jacket water will vary from 25 to 40 per cent. of the heat supplied by the fuel. The loss of heat in the exhaust gases, owing to their high temperature, will vary from 25 to 50 per cent. of the heat supplied, increasing as the jacket loss decreases.

The other main losses are those due to incomplete combustion of the fuel, heat radiated from the outer surfaces of the engine, and frictional losses in the mechanism of the engine.

Installation and Care of Internal Combustion Engines.—The general rules govering the installation of steam-power plant equipment apply to internal combustion engines. An engine should be installed in a well-lighted and ventilated room, which is free from dirt and dust. The engine room must be large enough so that there is sufficient space for easy access to any part of the engine so as to facilitate starting, oiling, inspection, and repair of all parts.

In installing oil engines, the fuel tank should be located outside the building and preferably underground. In any case the tank should be lower than the pipe to which it is connected in the engine room.

As the mixture of fuel and air is ignited inside the engine cylinder, the resulting explosion produces a shock of considerable magnitude on the engine mechanism, which in turn is transmitted to the foundation. This necessitates very carefully built foundations, which should be separated from the walls of the building, so that vibrations caused by the engine will not affect the building or the surrounding structures.

The exhaust piping should be as straight and as short as possible and the exhaust gases should discharge out of doors. The air supply is preferably taken from the outside.

Before an engine is started for the first time, all the working parts should be carefully examined and placed in proper condition.

The gas engine is not self-starting, as is the steam engine when steam is turned on. The reason for this is that the explosive mixture of fuel and air must be taken into the cylinder and compressed before it can give up energy by explosion. It is, therefore, necessary to set the engine in motion by some external means not employed in regular operation, before it will pick up its normal cycle.

Small engines are started by hand. This is accomplished by turning the fly-wheel over by hand in the direction of normal rotation until the engine picks up, or by turning it in opposite direction against compression and then snapping the igniter by hand. As it is difficult to pull over an engine by hand against compression throughout the whole cycle, some engines are provided with a starting cam, which can be shifted so as to engage the exhaust lever. This relieves the compression while cranking, as the exhaust port is open during the first part of the compression stroke. After the engine speeds up the starting cam is disengaged. Most small engines and also all engines for automobiles, tractors, and trucks are provided with starting cranks. Starting cranks are arranged so that, when turned in the direction of rotation of the engine, they grip the shaft. The starting crank is released as soon as the engine shaft turns faster than the crank.

As the size of the engine increases hand methods for starting cannot be used. Stationary gas and oil engines are usually started by compressed air. If the engine consists of two or more cylinders, this can be accomplished by shutting off the gas supply to one of the cylinders and running this cylinder with compressed air from a tank, in the same manner as a steam engine is operated with steam from a boiler. As soon as the other cylinders pick up their cycle of operations the compressed air is shut off and a mixture of fuel and air is admitted to the cylinder used in starting. With large gas engines of only one cylinder, the compressed air is admitted long enough to start the engine revolving, when the compressed air is shut off and the mixture of fuel and air is admitted. The air supply for starting is kept in tanks which are charged to a pressure of 50 to 150 lb. by a small compressor, driven either from the engine shaft, or by means of an auxiliary motor.

In electric central stations starting by electricity is the simplest. Electric starting systems are also used generally on modern automobiles as will be explained in Chapter XVI.

Before an internal combustion engine is started, the fuel supply should be examined, the ignition system tested, the lubricating devices examined and placed in proper working condition, the load disconnected from the engine, and the spark mechanism retarded to the starting position. In starting an engine by hand cranking, the operator should always pull up on the crank. As soon as the engine starts, the spark should be advanced to the running position and the engine connected to its load.

To stop an engine, the fuel valve is closed, the switch controlling the ignition system is opened, the lubricators and oil cups are closed, and the jacket water is turned off. In cold weather the water from the engine jackets should be drained to prevent freezing. Before leaving the engine it should be cleaned, all parts examined and put in order ready for starting up.

The operation and the economy of an internal combustion engine is greatly influenced by the proper timing of the valves and of the point of ignition. The exact setting of the valves and of the point of ignition depends upon the speed of the engine and upon the fuel used.

The exhaust valves should open before the end of the power stroke and generally from 25° to 40° before the crank reaches the outer or crank-end dead center. This is necessary to prevent loss of power when the piston starts on the exhaust stroke. The time of opening of the exhaust valve must be earlier for high-speed than for slow-speed engines. The exhaust valve should remain open until the crank has turned 5° to 12° beyond the completion of the exhaust stroke. The suction stroke follows the exhaust stroke, and, in order to prevent the mixing of the fresh charge with the burnt gases, the inlet valve should open about 3° after the exhaust valve closes. The time of closing of the inlet valve should be after the crank has turned 10° to 25° beyond the completion of the suction stroke. To ascertain if the valves of an engine are properly timed, the fly-wheel should be turned over slowly and the time of opening and closing of each valve noted. The proper setting of the valves can be accomplished by changing the length of the valve push rods or by changing the timing of the valve gear shaft. If for any reason the gears are removed on the crank shaft or on the valve gear shaft, care should be taken that they are properly replaced, as one tooth out of place will throw the valve mechanism out of time.

The exact point of ignition depends upon the system of ignition, the speed of the engine, the compression, and upon the fuel used. Proper ignition timing can best be determined by means of an indicator. Indicator cards showing early, late, and proper ignition are illustrated in Fig. 173.

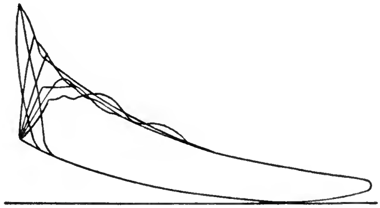


FIG. 173.—Indicator cards showing early, late, and proper ignition.

If an engine runs well at no-load but will not carry its rated load, the fault may be due to: poor compression, poor fuel, defective ignition, poor timing of ignition, incorrect valve setting, incorrect mixture, leaky inlet or exhaust valves, too much friction at bearings, or to the engine being too small for the rated load.

Premature ignition, usually called preignition, is due to the deposition of carbon or soot on the walls of the cylinder, the compression being too high for the fuel used; by over-heating of the piston, exhaust valve, or of some poorly jacketed part.

Best results will be secured if the operation of an engine is placed in charge of one man who is held responsible for the condition of the motor.

Problems

1. Can an economical internal combustion engine be developed to operate upon a one-stroke cycle? Give reasons for your answer.

2. How does the combustion of the mixture in an Otto cycle engine compare with the explosion of gunpowder?

3. Under what conditions is the two-stroke cycle engine most practical?

4. Why are higher compression pressures more practical with blast furnace gas than with natural gas.

5. At what temperature should the water in the jacket of a gas engine be maintained? Give reasons for the temperature used.

6. Compare poppet and slide valves for internal combustion engines.

7. Why will an automatically operated inlet valve decrease the power of a gas engine?

8. An oil engine is found to deliver 150 horsepower when tested at sea level. Will this engine develop the same power at Denver, Colorado? Give reasons for your answer.

9. Explain the difference between preignition and backfiring.

10. Check and correct the valve setting of some internal combustion engine.

11. Failure of an internal combustion engine to start is due to what causes? Explain in detail causes and remedies.

12. If an internal combustion engine slows down and stops, apparently without cause, where would you look for trouble? Explain in detail.

13. Black smoke issues from the exhaust of a gas engine. What is this an indication of? What causes blue smoke at the exhaust?

14. What will cause the deposition of carbon on the cylinder walls?

CHAPTER XII

INTERNAL COMBUSTION ENGINE FUELS AND GAS PRODUCERS

Fuels

Classification of Fuels.—Solid, liquid, and gaseous fuels are used in internal combustion engines. The value of a fuel depends upon its heating value, upon its cost, upon the rapidity with which it burns, and upon the cost of preparing it for use in the gas engine cylinder. The fuel must be capable of being transformed into a vapor or a gas before entering the engine cylinder, must readily combine with air to form an explosive mixture, and should leave no residue or ash after combustion.

Gaseous fuels are the simplest for use in internal combustion engines. The fuel in the gaseous state requires simply a mixing valve to proportion the air and the fuel before the mixture enters the engine cylinder. For this reason when a suitable gaseous fuel can be obtained at a low cost it is generally preferred.

Solid fuels in their natural state cannot be used for internal combustion engines. The chief difficulty experienced in their use is from the ash or residue which remains after combustion. Several attempts have been made to inject coal dust directly into the cylinder of an internal combustion engine, but the resulting ash seriously interferes with the operation. Gunpowder as a fuel has also been attempted, but has not proved successful. The only successful method of utilizing the energy of solid fuels at the present time is to transform the fuel from the solid to the gaseous state. The gas producer, to be explained later, is one of the most practical means by which this transformation is accomplished. The use of solid fuel requires considerable extra equipment, but has proved practical in many instances.

Liquid fuels are comparatively inexpensive in certain localities, are easily transported, and large quantities of such fuels may be stored in a comparatively small space. Petroleum distillates are used most commonly in internal combustion engines although alcohol, tar, tar oil, shale oil, and phenoloid (liquid fuel from blast furnaces) are also employed to some extent.

The Heating Value of a Fuel.—The heat content of a liquid or gaseous fuel is an important index of its value, as is the case of solid fuels discussed in Chapter II. This property is measured in much the same manner as is the heating value of coal. The fuel is burned in some form of calorimeter and the heat liberated is measured by the amount of heat absorbed by the water which surrounds the combustion vessel or chamber of the calorimeter. In Fig. 174 is illustrated a calorimeter for determining the heating value of gaseous fuels. This type of calorimeter with special equipment is also used for testing light liquid fuels.

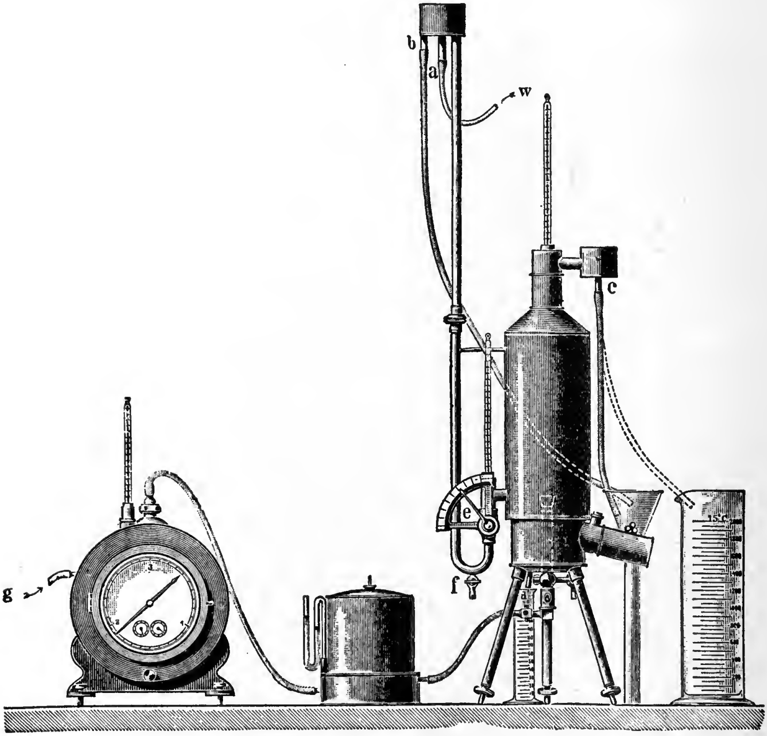


Fig. 174.—Gas Calorimeter.

The apparatus (Fig. 174) is designed for determining the number of heat units in a certain volume of gas, as a cubic foot or a cubic meter.

The gas enters the meter at *g* and passes thence through the pressure regulator to the calorimeter proper, where the gas burns at the burner shown in dotted outline.

The products of combustion rise to the top where they enter and pass down through a double row of pipes which are surrounded by circulating water and leave at the exit flue at the base.

The water entering at *a*, passes through the regulating cock *e*, thence around the tubes and issues at *c*, whence it flows into the measuring glass.

Thermometers register the temperatures of the gases and the water entering and leaving the calorimeter.

Knowing the volume of gas burned, the quantity of water collected, and the temperatures above noted, a simple calculation gives the heating value of the gas.

Selection of a Fuel.—While the heating value of a fuel is an important index of its value several other properties are usually considered.

The value of a solid fuel depends upon the percentage of water it contains, the amount of ash, the tar-forming ingredients, and whether it is of a coking or non-coking variety. Moisture simply dilutes the gas generated and consequently lowers its heating value per cubic foot. A high percentage of ash in the fuel requires more frequent cleaning of the producer and often causes a partial stoppage of the air supply. Coking fuels require constant breaking up of the charge with the consequent hindrance in the operation of the producer. The formation of tar, which results when bituminous or high volatile coals are gasified, requires cleaning of the gas before it enters the gas engine cylinder. Tar in the cylinder leaves a large deposit of soot, which interferes with the operation of the engine. Anthracite coal and coke are perhaps the ideal solid fuels for gas producers, because of the absence of tar, although other varieties of coal and lignite are used to a certain extent.

The quality of a liquid fuel depends upon its specific gravity, flash point, water content, cold test, color, sulphur content, presence of acids, and residue.

By specific gravity is meant the relation existing between the weight of any substance and the weight of an equal volume or bulk of water. The Baumé hydrometer (Fig. 175) is generally used for this determination. This instrument carries an arbitrary scale and sinks to a depth corresponding to the density of the liquid in which it floats. Table 7 shows the relation existing between the Baumé hydrometer scale, the specific gravity, and the weight of liquid fuels in pounds per gallon. Formerly liquid fuels were judged mainly by their specific gravity. In the case of blended fuels, specific gravity is not an accurate indication of its quality.

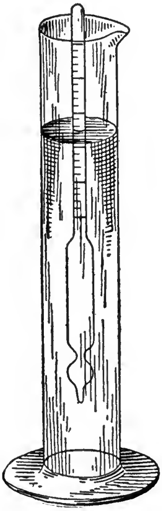


FIG. 175.—Baumé hydrometer.

The flash point of a liquid fuel is the lowest temperature at which the vapors arising therefrom will ignite when a small test flame is brought near its surface. The flash point is an index of the volatile constituents of a fuel.

The cold test is the lowest temperature at which a liquid fuel will pour. Upon this property depends the free circulation of liquid fuels through pipes.

Gaseous fuels to be suitable for internal combustion engines must be free from dust, tar, sulphur vapors, and other impurities.

Distillates of Crude Petroleum.—The so-called distillates of crude petroleum are obtained by boiling or refining crude petroleum, and condensing the vapors which are driven off at various temperatures. Crude petroleum is a mineral oil which is found in greatest quantities in the United States, Russia, Mexico, and Rumania. The exact composition of crude petroleum varies in different localities. It is made up mainly of carbon and of hydrogen, in the ratio of about two-thirds carbon to one-third hydrogen. Crude petroleum in certain localities has a paraffin base; that is, it yields a solid paraffin residue. Other petroleums with an asphalt base yield an asphalt residue. The specific gravity of petroleum oils from different fields varies between 0.800 and 0.970.

The vapors which are condensed into gasoline are driven off at temperatures of 140 to 160°F. The various grades of kerosene are the condensed vapors, driven off at temperatures of

Table 7.—Specific Gravity and Baumé Scale

Specific gravity	Degrees Baumé	Pounds per gallon	Specific gravity	Degrees Baumé	Pounds per gallon
1.000	10	8.336	0.775	51	6.462
0.993	11	8.277	0.771	52	6.428
0.986	12	8.220	0.767	53	6.394
0.979	13	8.161	0.763	54	6.358
0.972	14	8.104	0.759	55	6.324
0.966	15	8.051	0.755	56	6.290
0.959	16	7.997	0.751	57	6.258
0.953	17	7.944	0.747	58	6.212
0.947	18	7.891	0.743	59	6.195
0.940	19	7.837	0.739	60	6.163
0.934	20	7.785	0.736	61	6.133
0.928	21	7.736	0.732	62	6.101
0.922	22	7.687	0.728	63	6.070
0.916	23	7.638	0.724	64	6.038
0.911	24	7.590	0.721	65	6.006
0.905	25	7.541	0.717	66	5.975
0.899	26	7.493	0.713	67	5.946
0.893	27	7.444	0.710	68	5.916
0.887	28	7.395	0.706	69	5.886
0.881	29	7.347	0.703	70	5.856
0.876	30	7.298	0.699	71	5.827
0.870	31	7.254	0.696	72	5.797
0.865	32	7.210	0.692	73	5.771
0.860	33	7.166	0.689	74	5.743
0.854	34	7.122	0.686	75	5.715
0.849	35	7.079	0.682	76	5.688
0.844	36	7.038	0.679	77	5.659
0.840	37	6.998	0.676	78	5.632
0.835	38	6.696	0.672	79	5.603
0.830	39	6.918	0.669	80	5.576
0.825	40	6.878	0.666	81	5.548
0.820	41	6.839	0.662	82	5.517
0.816	42	6.804	0.658	83	5.487
0.811	43	6.760	0.655	84	5.457
0.806	44	6.721	0.651	85	5.427
0.802	45	6.683	0.648	86	5.402
0.797	46	6.644	0.645	87	5.374
0.793	47	6.608	0.642	88	5.353
0.788	48	6.571	0.639	89	5.316
0.784	49	6.534	0.636	90	5.304
0.779	50	6.498			

250 to 400°, and the heavy oils are driven off at still higher temperatures.

Gasoline.—Of all petroleum distillates, gasoline is the most important fuel for automobiles, airplanes, and small stationary and portable internal combustion engines. The consumption of gasoline has increased in the United States more than 700 per cent. during the past ten years. The yield of gasoline, however, is very small in comparison with the heavier distillates. By refining American petroleum, an average of less than 5 per cent. of gasoline is obtained and usually about 50 per cent. of kerosene. This makes gasoline more expensive than other petroleum fuels.

Gasolines may be classified as: (1) straight refinery, (2) cracked, (3) casing head.

The straight refinery method of manufacturing gasoline from crude petroleum is to heat the crude oil in a closed retort, called a still, then cooling and condensing the vapors given off. Destructive distillation, or cracking, is prevented by keeping down the temperature within the still either by placing the still under a partial vacuum or by allowing steam to bubble through the crude oil when distilling.

Cracked gasolines are obtained by subjecting petroleum oils of high boiling point to high temperatures and pressure; the heavy oil decomposes and cracked gasoline is recovered from the distillate.

Natural gas gasoline is obtained from natural gas either by the compression or the absorption methods. The compression process is usually applied to wet gas, called casing head gas; that is, to gas which is produced from the same sands as petroleum oil. The absorption process can be used with ordinary natural gas. A gasoline similar to casing head gasoline is also being manufactured in refineries by the compression process from the very light vapors which are driven off when the stills are first heated.

Commercial gasoline is usually a physical blend of these various grades. Its density varies from 57 to 85 degrees Baumé (0.65 to 0.75 specific gravity), depending upon its composition. The weight of gasoline varies from 5.4 to 6.2 pounds per gallon. Its heating value is about 19,000 B.t.u. per pound. The flash point of gasoline varies from 10 to 20°F. This means that gases are liberated which form an inflammable vapor at low temperatures provided a sufficient supply of air is present. For this reason care must be taken in the handling of gasoline. A good storage tank free from leaks and placed underground contributes greatly to the safety as well as to the economical use of gasoline. When filling a gasoline storage tank or in handling gasoline, care must be taken not to have any unprotected flame nearby. In case of fire it is best to extinguish the flame by means of wet sawdust or a special fire extinguisher.

Kerosene.—Kerosene, which can be secured in greater quantities than gasoline and which has a rather limited market, ranks next to gasoline among the products of crude petroleum for use in oil engines. Its density varies from 41 to 49 degrees Baumé (0.78 to 0.82 specific gravity). Its flash point is 70 to 150 degrees depending upon the grade, and its heating value per pound is about 18,500 B.t.u. Kerosene is less volatile than gasoline, is safer to handle and store, does not evaporate so rapidly, but requires preheating to produce rapid evaporation. Kerosene is quite satisfactory as a fuel for engines operating under constant loads and speeds. Any gasoline engine can be operated with kerosene fuel provided it is started and run with gasoline until the cylinder walls become hot. Hot bulb engines will start on kerosene.

Crude Oil.—Distillate and fuel oils are the heavier petroleum products which are used as fuels in Diesel or semi-Diesel types of internal combustion engines. These fuels have a high flash point and a heating value of 18,000 to 20,000 B.t.u. per pound. The qualities of these oils are based principally upon their heating value and to a certain extent upon their specific gravity.

Alcohol.—Alcohol as a fuel for gas-engine use has many advantages as compared with the petroleum distillates. It is less dangerous than gasoline, its products of combustion are odorless, and it lends itself to greater compression pressures than do the various petroleum fuels. Experiments show that an engine designed to stand the compression pressures before ignition most suitable for alcohol will develop about 30 per cent. more power than a gasoline engine of the same size, stroke, and speed.

Several years ago, when the internal revenue tax was removed from alcohol, so denatured as to destroy its character as a beverage, it was expected that denatured alcohol would become a very important fuel for use in gas engines. Its price up to this date, however, has been so much higher than that of gasoline, the most expensive of petroleum fuels, that the use of alcohol in gas engines is out of the question. It is possible that, as the cost of the petroleum distillates increases, and processes are developed for producing denatured alcohol at a low price, the alcohol engine will come into prominence as a motor.

American denatured alcohol consists of 100 volumes of ethyl (grain) alcohol, mixed with ten volumes of methyl (wood) alcohol, and with one-half a volume of benzol.

The specific gravity of denatured alcohol is about 0.795 and its calorific value is about two-thirds that of petroleum fuels. Alcohol requires less air for combustion than do petroleum fuels. Theoretically, the calorific value of a cubic foot of explosive mixtures of alcohol and of gasoline is about the same. Actual tests show that the fuel economy per horsepower is about the same for both fuels provided the compression pressures before ignition are best suited for the particular fuel used. In gasoline engines compression pressures of about 75 lb. are used, while the alcohol engine gives best results, as far as economy and capacity are concerned, when the compression pressure before ignition is about 180 lb. per square inch.

Benzol.—Benzol is a liquid fuel derived from the distillation of coal. In the pure state it has a density of about 29 degrees Baumé (0.88 specific gravity) and a heating value of about 17,200 B.t.u. per pound. When mixed with various proportions of gasoline or of alcohol a desirable fuel results. A fifty per cent. mixture of benzol and alcohol has been successfully used as a fuel. Commercial benzol contains about 90 per cent. benzol while the remaining constituents are other minor coal tar derivatives.

Shale Oil.—Shale oil is obtained from the destructive distillation of shale in vertical retorts in which the shale is exposed to a temperature of about 900°F. The crude shale oil has a specific gravity of 0.86 to 0.89 and yields, by refining, oils which are suitable for use in internal combustion engines of special design.

Fuel Gases.—The fuel gases suitable for internal combustion engines are blast-funace gas, coke-oven gas, natural gas, and producer gas. Internal combustion engines can also be operated on illuminating gas, acetylene, and oil gas; but these fuel gases are usually too expensive.

Illuminating gas is manufactured by distillation of bituminous coal and has a heating value of about 600 B.t.u. per cubic foot.

Acetylene gas is formed when calcium carbide is decomposed by water and has a heating value of about 1,500 B.t.u. per cubic foot.

Oil gas is produced by vaporizing crude petroleum.

Blast-furnace Gas.—Blast-furnace gas is made by the combustion of coke during the production of pig iron. The gas, after leaving the top of blast furnaces, can be purified and used for operating internal combustion engines. Blast furnace-gas has a heating value of only about 100 B.t.u. per cubic foot, but can be compressed to high pressures with the resulting high efficiency if used in internal combustion engines operating on the Otto cycle. From 120,000 to 180,000 cubic feet of blast-furnace gas are generated at the production of each ton of pig-iron, and this is available for the generation of power as well as for the various heating processes required in the plant. Blast-furnace gas must be thoroughly cleaned of all fine dust and of metallic vapors before it is used in gas engines.

Coke-oven Gas.—Coke-oven gas has a heating value of about 600 B.t.u. per cubic foot and when free from tar is suitable as a fuel for internal combustion engines. Modern coke-oven plants yield considerable gas for power purposes, as only about 60 per cent. of the gas generated in the coke ovens is used as fuel for the coking process.

Natural Gas.—Natural gas is found near practically all oil fields and has been very successful as a gas engine fuel. The heating value of natural gas varies ordinarily from 900 to 1000 B.t.u. per cubic foot. On account of the high hydrogen content of natural gas, engines utilizing this fuel must operate at low compression pressures in order to prevent preignition. Owing to the need of natural gas as a fuel for industrial and household use and to the uncertainty of a continued supply, its utilization for the generation of power is limited to very few localities.

Producer Gas.—Producer gas is manufactured from solid fuel in a brick lined vessel, called a gas producer. The gas producer is blown continously with a mixture of air and steam, in definite proportions, generating a combustible gas, which is suitable for use in internal combustion engines or for heating. Producer gas can be manufactured from charcoal, coke, anthracite coal, bituminous coal, lignite, peat, or wood. Producers operating on anthracite coal or coke have been more satisfactory than those using bituminous coal or lignite, as anthracite coal producer gas contains very little tar and the plant does not have to be provided with elaborate scrubbing systems for cleaning the gas.

The amount of gas generated per pound of fuel depends upon the fuel used. Producers using lignite will usually generate less than 40 cubic feet of gas per pound of fuel. With bituminous coal, the gas generated per pound of fuel will be about 65 cubic feet, with anthracite about 75, and with coke near 90 cubic feet of gas will be produced.

Anthracite producer gas has an average heating value of about 130 B.t.u. per cubic foot and contains approximately: 9 per cent. of hydrogen, 24 per cent. of carbon monoxide, 5 per cent. of carbon dioxide, 2 per cent. of hydrocarbons, and about 60 per cent. of nitrogen. Bituminous producer gas has a heat of combustion of about 140 B.t.u. and contains approximately: 12 per cent. of hydrogen, 20 per cent. of carbon monoxide, 8 per cent. of carbon dioxide, 3 per cent. of hydrocarbons, and about 57 per cent. of nitrogen.

Internal combustion engines using producer gas can be operated at a compression pressure before ignition of about 160 pounds per square inch and will produce a horsepower for about 75 cubic feet of gas, which can be generated in a producer by the gasification of about one pound of coal.

GAS PRODUCERS

Details of Gas Producers.—A gas producer is a brick-lined air-tight steel plate cylinder arranged with a grate to hold a thick bed of fuel, a hopper and an ash pit to receive the fuel and the non-combustible material respectively, means for supplying a mixture of air and steam to the fuel bed, a gas outlet, and gas cleaning apparatus. Producers are usually provided with poke holes and shaking grates for breaking up and for maintaining the fuel bed in uniform condition.

Details of a typical producer generator are illustrated in Fig. 176. Fuel is charged into the retort *C* and is admitted to the shell of the generator by means of a quick-opening gate valve. The retort *C* is provided with a water-sealed cover, this arrangement enabling the operator to charge the producer while the plant is in operation, without the danger of admitting air or of allowing gas to escape. Coal entering the shell is distributed by means of the hood *J′*, the inside of which serves as a gas collector. The gas outlet is at *J*. A swinging grate *Z* supports the fuel bed and is suspended from the shell by chains. The shaking motion of the grate is produced by the hand lever *L*. Doors are provided at the bottom for the removal of ashes. The generator is provided with peep holes and poke holes for observing and maintaining the fuel bed in the proper condition. The mixture of steam and air enters at *A*. The temperatures of the various zones are approximately as indicated in Fig. 176.

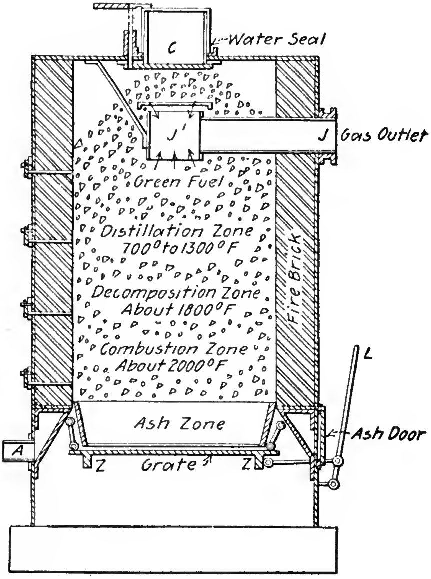


FIG. 176.—Gas producer generator.

Classification of Gas Producers.—Producers are classified by the manner in which the mixture of air and steam is caused to pass through the producer and gas cleaning apparatus.

In the suction types of producers the air is drawn through the producer and gas-cleaning apparatus by the suction formed in the engine cylinder. The rate of gas formation in this type is automatically controlled by the demand of the engine. This type of gas producer is inexpensive and is suitable only for small installations.

In the pressure types of producers the mixture of air and steam is forced through the fuel bed of the producer by means of a fan. The amount of gas generated in this case is independent of the amount used by the engine.

In a third type, called combination producer, a fan is placed between the producer and the engine which delivers the gas to the engine or to a gas holder under pressure. The producer proper in this case operates as a suction producer, but the amount of gas generated is independent of the engine's demand.

Gas producers are also classified with reference to the fuel gasified. Anthracite producers are usually of the suction type, the draft being produced by the suction of the engine piston. Bituminous producers are of the pressure or of the combination types and are provided with special scrubbers and purifiers for removing tar and other impurities.

Suction Gas Producers.—A simple suction gas producer suitable for anthracite coal is illustrated in Fig. 177. The generator *A* of the producer is a cast iron or steel shell with a grate below and a fuel hopper above. Steam for the blast is generated in a vaporizer, which is either arranged around the top of the producer or is independent of, but attached to, the producer proper. The mixture of air and steam enters at the bottom of the fuel bed, a valve regulating the proportion of air and steam. The gas leaving the producer is cooled and purified in a coke-filled wet scrubber *S* and passes to the engine cylinder *C*.

In some suction producer plants the gas is cooled and cleaned of dust in a water-sprayed coke scrubber, after which it is allowed to pass through a dry scrubber on its way to the engine. The dry scrubber is filled with shavings, excelsior, and iron turnings and is intended to remove sulphurous fumes from the gas.

The hand-operated fan *B* (Fig. 177) is used to furnish draft during the starting of the fires. When the engine is in operation the draft from the fan *B* is not necessary. A producer is also provided with a change valve, which is used to discharge the poor gases to the atmosphere when the fire is started up.

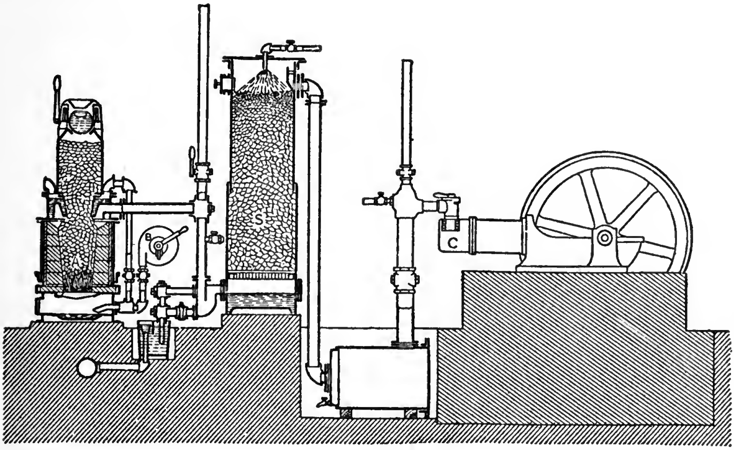


Fig. 177.—Suction producer plant.

Pressure Gas Producers.—One type of pressure producer, called the water-bottom producer, is illustrated in Fig. 178. The grate in this case is dispensed with and the ashes drop into a water seal at the base of the producer. The blast is admitted to the center of the producer by a steam jet blower *B*. The fuel is discharged from the hopper *D* into the chamber *E*, from which it is distributed uniformly by the device *F*. Poke holes are provided at *G* and at *H* for breaking up the fuel bed. The gas leaving the producer at *C* enters scrubbers, tar extractors, and other purifiers on its way to the engine cylinder. The water-bottom type of producer is advantageous in that the ashes can be removed conveniently while the producer is in operation. Some water-bottom pressure producers are provided with an automatic fuel-feeding device.

Combination Producers.—Combination producer plants have a blower placed between the producer and the engine cylinder. Some plants of this type are similar to the producers described and are equipped with elaborate scrubbers and purifiers when operated with low grade fuels.

In the down-draft double furnace producer, illustrated in Fig. 179, the formation of tar is prevented by carrying the gases, which are distilled from the fresh fuel in the upper strata, through the hottest zone at the lower part of the producer.

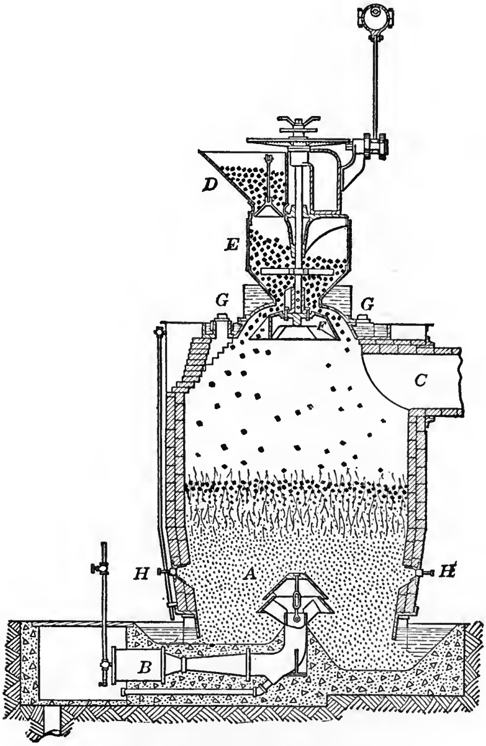


Fig. 178.—Pressure gas producer.

The cleaning apparatus used with this type of plant consists only of a wet and dry scrubber.

In starting the down-draft double furnace producer the fires are kindled with coke and wood in both generators and the blower is started, leaving open the top doors *H* and *I*, and valves *A*, *B*, *G*, and *C*. Valve *D* is closed. As soon as the fires are thoroughly kindled, steam is admitted to the top of the generators at *F* and

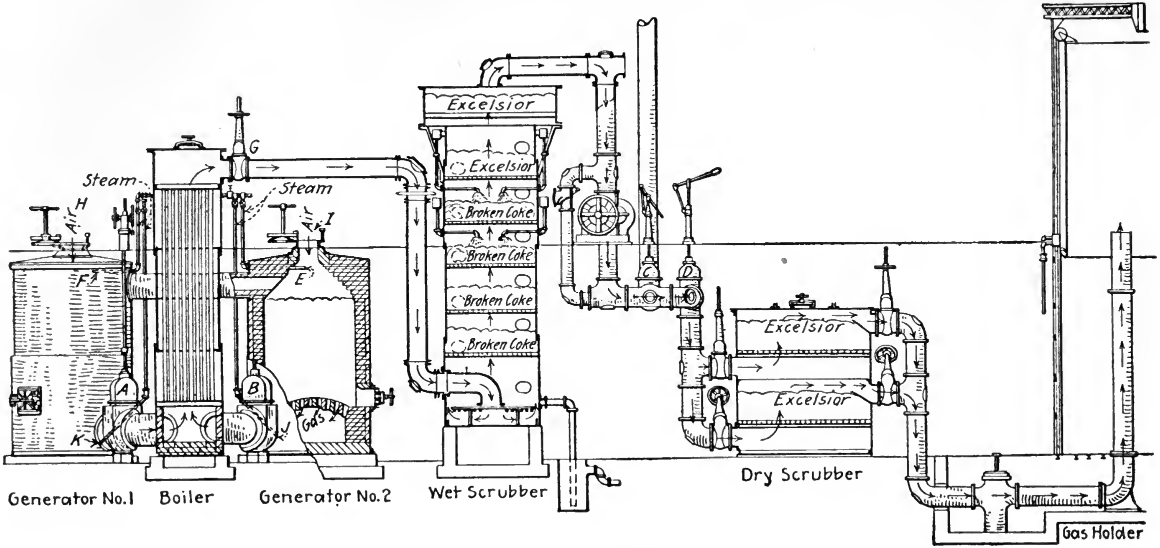


FIG. 179.—Down-draft double furnace producer.

E, and mingles with the air admitted through top doors *H* and *I*, which the operation of the blower draws down through the fresh charge of coal and then through the hot fuel bed beneath. The gas produced is then drawn down through the grates and ash pits of both generators, up through the vertical boiler, through the valve *G*, through the wet scrubber, and blower. When valve *C* is closed and valve *D* is opened the gas is pushed by the blower through the dry scrubber and to the gas holder. The gas from the gas holder is delivered to the engine cylinder.

Rating of Gas Producers.—The capacity of a gas producer is expressed by the number of pounds of fuel it can gasify per hour or in horsepower if the gas is generated for power purposes. The gasifying capacity of a producer depends upon its design and upon the quality of the fuel used. The rating in horsepower is incorrect because no mechanical work is done by the producer and there is no definite relation between the capacity of a producer and the power developed by an internal combustion engine. There is at present no standard method for rating gas producers.

Factors Influencing Producer Operation.—One of the most important factors to be considered in the selection of a gas-producer fuel is its volatile constituents. The fuel that produces tar and lampblack in large quantities will require complicated scrubbing systems, or producers of special design. This will in either case increase the first cost of the plant as well as the cost of the upkeep of engines and pipe lines. The amount of tar-forming gases is small with anthracite coal, but is considerable in the case of most bituminous coals and lower grades of solid fuels.

The kind of ash is also of importance. If the ash fuses or fluxes to a clinker, the proportion of steam to air in the blast must be increased to reduce the temperature of the fuel bed. This decrease in temperature reduces the percentage of combustible carbon monoxide formed in the producer. The use of too much steam in the producer results in the formation of a gas which has considerable hydrogen. This means that when used in internal combustion engines the gas cannot be compressed to as high a pressure as producer gas which has little hydrogen.

Clinker formation is also serious because it obstructs the gas passages, requiring increased blast pressure to allow the air to pass through the fuel bed. Uniform conditions during producer operation and careful poking will reduce the difficulties from clinker.

The size of coal used influences the capacity and efficiency of a gas producer. If the coal is too large, too little surface is offered for gasification and the producer efficiency is reduced. A nut-size of bituminous coal is best while the pea-size anthracite will give good results. If the coal is too fine, the resistance through the fuel bed is increased, requiring greater blast pressure, and this reduces the capacity of the producer.

The grate area, the rate of gasification, and the depth of the fuel bed are affected by the character of the fuel, the lower grade fuels requiring a larger grate area, slower rates of gasification, and deeper fuel beds.

Some form of gas calorimeter will prove very useful in the daily operation of gas producers.

Problems

1. An analysis of a gas by the gas calorimeter (Fig. 174) gave the following readings: Gas passed through meter 3 cubic feet, water collected 85 pounds, inlet temperature 65°F., outlet temperature 84°F. Calculate the heating value of the gas in B.t.u. per cubic foot.

2. Compare the relative values of gasoline, kerosene, alcohol, and crude petroleum for use in internal combustion engines.

3. At what price must the ordinary illuminating gas sell in order to compete with natural gas at 50 cents per thousand cubic feet?

4. Under what conditions is the gas-producer plant most suitable for power generation?

CHAPTER XIII

AUXILIARIES FOR INTERNAL COMBUSTION ENGINES

CARBURETORS

Principles of Carburetion.—To successfully operate an internal combustion engine on liquid fuel it is necessary to vaporize the fuel and mix it with air in the correct proportions for use in the engine cylinder. This process of vaporizing and mixing the fuel with air is known as carburetion. The function of a carburetor is automatically to vaporize the liquid fuel, and mix it with air in the correct proportions by weight for use in the engine cylinder and at all speeds of the engine.

A mixture too rich, that is, having too large a proportion of gasoline to air, will give off a black, odorous exhaust due to the fact that some of the gases are unburned. A mixture too lean, that is, having insufficient gasoline, is slow burning and, consequently, may result in back-firing through the carburetor. A lean mixture is accompanied also by the heating of the motor and by a loss of power.

Carburetors.—Practically all modern carburetors use some form of spray nozzle for vaporizing the fuel. A throat, or Venturi tube, is usually made use of to increase the velocity of the air at the spray nozzle, thereby increasing the spray of gasoline from the nozzle.

Simple Carburetors or Mixer Valves.—The simpler forms of carburetors which are used on stationary and constant speed engines are called mixer valves. Mixer valves are not suitable for variable speed motors.

Fig. 180 represents the constant level, or overflow cup, type of mixer valve. *B* represents the reservoir in which the constant level of fuel is kept. *A* is the supply pipe. Gasoline is forced by means of a pump, operated by the engine, through the pipe *A*. *O* is the overflow pipe the top of which is located just below the top of the nozzle *N*. Air enters at *C*, and on the suction stroke of the engine rushes past the nozzle *N*, picking up and mixing with the spray of gasoline which is regulated by the needle valve *V*. The valve *V* is the only adjustment on this mixer valve.

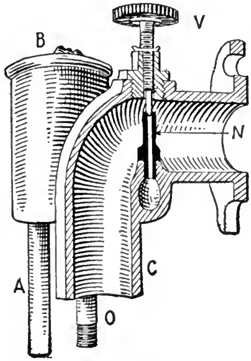


FIG. 180.—Mixer valve.

Float-feed Carburetors.—At present, some form of the float-feed type of carburetor is exclusively used on automobiles, trucks, and other variable speed motors. Float-feed carburetors are of two types: first, the concentric, in which the float chamber surrounds the mixing chamber, or is concentric with it; second, the eccentric, which has the float chamber and mixing chamber side by side. The concentric type keeps the fuel at the predetermined level much better than the eccentric carburetor. In the concentric type, the height of the fuel in the nozzle is not changed by road inclinations, whereas in the case of the eccentric type the fuel level may become very low or may be high enough to actually flow from the nozzle. Many of the successful modern carburetors are of eccentric type, because other advantages or conveniences more than offset the disadvantages mentioned above.

The Kingston Carburetor.—Fig. 181 represents a concentric float-feed type of carburetor. Gasoline enters at *G*, flowing past the valve *V* into the float chamber *W*. The valve *V* is connected to the float *F* by means of a lever pivoted near its center. When the gasoline reaches the correct level, the float is so set that it closes the valve *V* by means of the lever mentioned. The correct level of gasoline varies in different carburetors somewhere between $\frac{1}{32}$ and $\frac{1}{16}$ inch below the top of the spray nozzle. Air enters the carburetor at *A*, passes downward to the base of the carburetor, thence upward past the spray nozzle *J*, where it is mixed with the gasoline. The mixing chamber around *J* has a reduced area, called the throat or Venturi tube. This is arranged to increase the velocity of the air at this point, thereby producing more suction on the gasoline supply. *S* is the gasoline adjusting screw which regulates the supply of gasoline by regulating the neeedle valve at *J*. Turning the screw *S* to the right decreases and turning to the left increases the amount of fuel used. The quantity of mixture used is regulated by the throttle *E*.

As the speed of the engine increases, the velocity, but not the quantity, of the air in the Venturi increases and the suction on the gasoline becomes also greater. As a result of this, the actual supply of gasoline increases, making the mixture too rich. This is true with any simple carburetor, and therefore some means must be provided automatically to govern the supply of gasoline. Some carburetors employ auxiliary air valves, other types have compound nozzles, while several designs employ a combination of nozzles and Venturis.

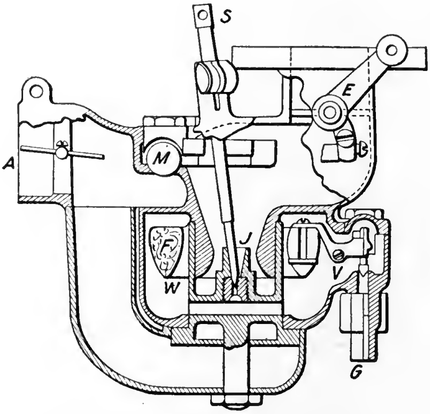


Fig. 181.—Kingston carburetor.

In the Kingston carburetor (Fig. 181) the desired result is obtained by an auxiliary air valve. This is a gravity valve consisting of several brass balls *M* arranged in a semicircle. The balls are so designed that when the suction becomes great enough to make the mixture too rich, the force of gravity on the balls will be overcome by this suction, and they will be lifted off their seats thereby admitting more air into the rich mixture. The auxiliary air does not pass the nozzle in this type of carburetor. The amount the balls lift off their seats is determined by the suction resulting from the speed of the engine.

Marvel Carburetor.—Fig. 182 represents a sectional view of the Marvel carburetor, which is of the multiple jet, eccentric float-feed type. There are two spray nozzles—one for low and one for high speeds.

The low speed nozzle with its throat is situated in the unobstructed air passage. The needle valve in this nozzle regulates the amount of gasoline. Turning the needle valve to right, or up, makes the mixture leaner and to the left, or down, makes the mixture richer. When the speed of the motor becomes great enough the resulting suction overcomes the force of the air valve spring, and the air valve opens, thereby cutting in the high speed nozzle into the air passage.

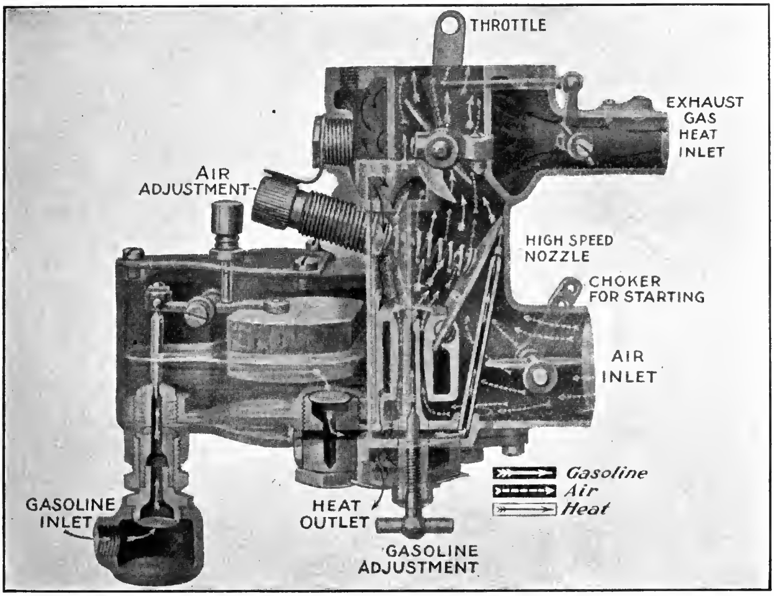


Fig. 182.—Marvel carburetor.

The high speed adjustment consists of tightening or loosening the tension on the spring, which controls the air valve. For a richer mixture, it would be necessary to turn the air adjustment screw to the right or clockwise, and vice versa for a leaner mixture.

The Marvel carburetor is rather distinctive in having a hot-air jacket surrounding the mixing chamber. Hot-air is taken off the exhaust manifold for heating the mixing chamber, thereby aiding in the vaporization of the fuel. By means of a butter-fly valve the operator is able to control the admission of heat to the hot-air jacket.

Stewart Carburetor.—Fig. 183 represents a Stewart carburetor. It is of the eccentric type and makes use of a metering pin to measure out the proper amount of gasoline for all motor speeds. The gasoline enters through the strainer *Z* into the float chamber *C* and past the needle valve *G*. From the float chamber, by means of the small passages, the fuel passes to the well surrounding the metering pin *P* and into the lower end of the aspirating tube.

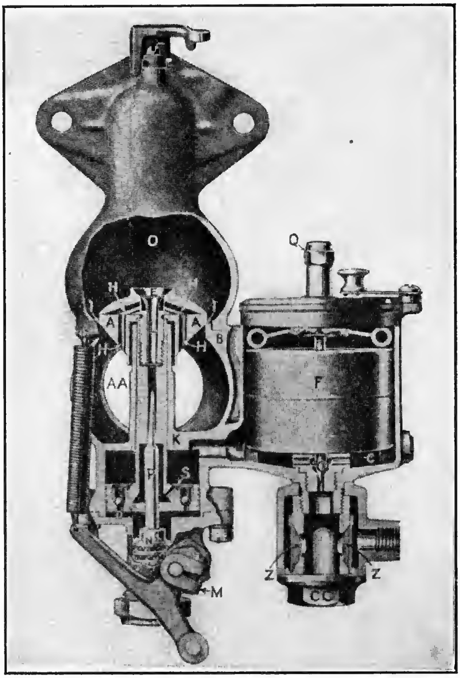


Fig. 183.—Stewart Carburetor.

At the lower engine speeds air enters the combining tube through the drilled passages *H*. In the combining tube it is mixed with the vaporized gasoline which has passed the metering pin into the aspirating tube. The passages *H* are open at all times, but the valve *A* is held closed by its weight until opened by the increased suction of the motor at the higher speeds. As *A* rises due to suction, the lower end of tube is less obstructed by the metering pin on account of the taper of the pin. This larger opening then permits of increased gasoline supply on the higher speeds. The taper of the pin is such that the proper amount of gasoline for all engine speeds is automatically taken care of.

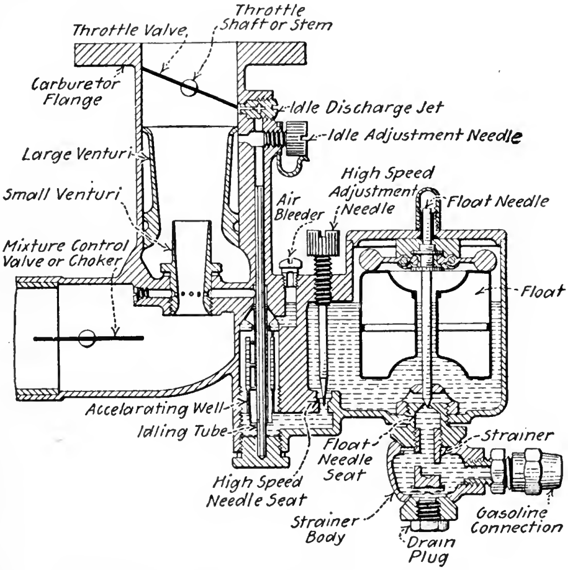


Fig. 184.—Stromberg plain-tube carburetor.

The only adjustment is by means of the worm *N* and pinion, by which the metering pin may be lowered for increased gasoline supply and raised for decreased supply. For starting in cold weather, it becomes necessary to increase the gasoline supply by adjusting the dash control. Usually the control is left part way out until the motor has become thoroughly warmed up.

The Stromberg Carburetor.—Fig. 184 represents the Stromberg plain-tube carburetor. A plain-tube carburetor is one in which both the air and the gasoline openings are fixed in size. In this carburetor the proper proportion of air to gasoline is maintained at all motor speeds by means of what the manufacturer calls an air bled jet. Air is taken in through the air bleeder and discharges into the gasoline channel before the gasoline reaches the jet holes in the Venturi. The air enters the tube at right angles to the flow of gasoline, thereby breaking up the flow of gasoline and producing a finely divided spray. When this spray reaches the jet holes and is discharged into the high velocity air stream, it is further broken up and enters as a very finely divided mist.

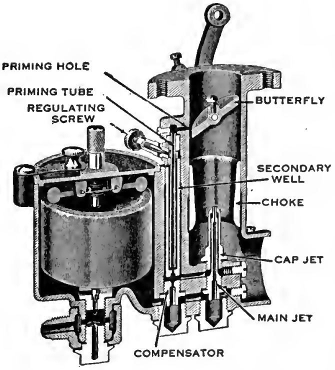


Fig. 185.—Zenith carburetor.

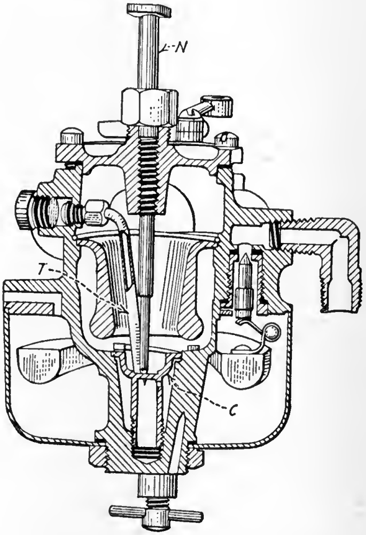


Fig. 186.—Holley carburetor.

An accelerating well is made use of to facilitate sudden increases in the speed of the motor.

The air when the engine is idling is drawn from below the throttle and mixes with the gasoline before reaching the idling jet. Under certain conditions, the suction draws gasoline from both idling jet and small Venturi, but as the throttle is opened more, the gasoline comes only from the Venturi. The function of the large Venturi is to aid in more finely dividing the gasoline vapor and further to mix it in the correct proportion with air.

The plain-tube Stromberg carburetor has two adjustments, one for low and one for high speeds. The low-speed screw adjusts the amount of air, and the high-speed screw regulates the quantity of gasoline.

Zenith Carburetor.—Fig. 185 represents a Zenith carburetor, which is of the eccentric float-feed type, and makes use of a compound nozzle to control automatically the amount of gasoline at all speeds of the motor.

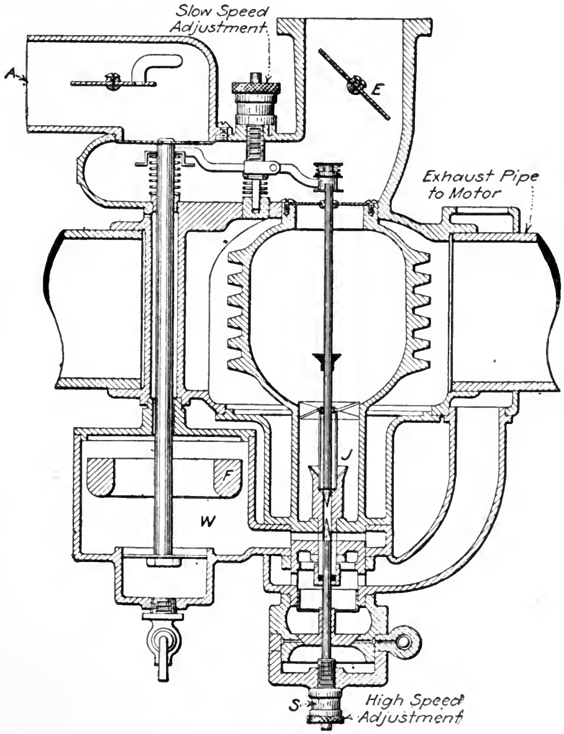


Fig. 187.—Kerosene carburetor.

The Holley Carburetor.—The Holley puddling type carburetor is illustrated in Fig. 186. The gasoline enters the float chamber in much the same manner as in any other carburetor. From the float chamber the gasoline passes to the needle valve. The fuel level is above the point of the needle valve and, consequently, the gasoline rises above the needle valve, fills the puddle cup *C*, and submerges the lower end of the copper tube *T*. The

Holley carburetor has only one source of air supply, there being no auxiliary air valve. All the air passing through the carburetor must pass over the puddle of gasoline in cup *C*.

The needle valve *N* regulates the amount of gasoline supplied to the well, and is the only adjustment on this carburetor.

Kerosene Carburetors.—The Kingston carburetor is used to some extent on engines operating with kerosene. When this is done, there are two separate and distinct carburetors connected by a three-way valve to the intake manifold. One of the carburetors is adjusted for gasoline and is used in starting; the other is adjusted for kerosene. After the engine is started and warmed up, the three-way valve is turned and the kerosene carburetor is connected with the intake manifold.

Another form of carburetor for burning heavy fuels is illustrated in Fig. 187. A connection from the exhaust pipe heats the bowl of the carburetor. This heat is necessary in order to vaporize the heavier fuels. Above the needle valve *J* is placed a set of stationary blades resembling the rotor of a windmill. The high velocity air stream laden with particles of unvaporized kerosene strikes these blades and is given a whirling effect. This throws the particles of fuel, due to their inertia, against the sides of the heated bowl and vaporizes them so that they can be mixed properly with the air for use in the cylinder. This carburetor has two needle valves, two adjustments, as noted in Fig. 187, and also an auxiliary air valve.

IGNITION SYSTEMS

For igniting the fuel charge in an internal combustion engine two methods are employed: the electric spark, which is most commonly used, and the automatic ignition system, which is produced by the heat to which the air or the mixture of air and fuel in the cylinder is subjected.

In some of the older makes of engines the hot tube system is employed. The tube, open at one end and closed at the other, is made of porcelain or of some nickel alloy. The closed end of the tube is heated by a Bunsen burner. During the compression stroke a portion of the mixture is forced into the tube and is ignited by the hot walls. The walls of the tube are then kept hot by heat caused from the explosions. Low first cost and low upkeep are the only points in favor of this system, but they are more than offset by the difficulty in regulating the time of ignition.

Electric Ignition Systems.—Two electric ignition systems are in use, the make-and-break and the jump-spark. In the case of the make-and-break system, the spark is similar to that produced when one electric wire connected to a battery is drawn across another, or to the spark produced by the opening of a switch. The spark in this system is produced by the contact and quick separation of metallic points located within the clearance space of the cylinder. In the jump-spark system, a current of high voltage is used which jumps across a small air gap within the clearance space of the cylinder.

The Make-and-break System of Ignition.—The principle of the make-and-break system of ignition is illustrated in Fig. 188. *B* is the battery which supplies the electric current for ignition. *C* is an inductance spark coil, often called a kick coil. It consists of a bundle of soft iron wires, called the core, surrounded by many turns of insulated copper wire through which the current passes. On account of the inductive action of such a coil, the spark is greatly intensified, producing a strong arc from a battery of low voltage. *S* is a stationary electrode well insulated from the engine, and *M* a movable electrode not insulated from the engine. Both electrodes are set in the combustion space of the cylinder.

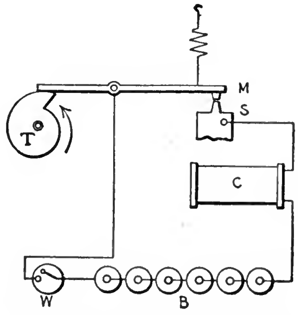


FIG. 188.—Make-and-break ignition system.

The contact points of the two electrodes are brought together by means of the cam *T* operated by the valve gear shaft of the engine. When the switch *W* is closed current will flow through the circuit as soon as the contact points of the electrodes are brought together by the cam *T*. A sudden breaking of the contact, aided by a spring, causes a spark to pass between the points which ignites the mixture. The more rapidly the electrodes are separated the better is the spark produced.

The contact between the two electrodes of the make-and-break system may also be made by sliding one contact point over the other. This type is known as the wipe-spark igniter and is illustrated in Fig. 189. *B* is the stationary insulated electrode and *A* is the movable electrode. *B* is made in the form of a spring and may be moved toward the electrode *A* by means of a screw. The wiping action of this igniter keeps the points clean at all times.

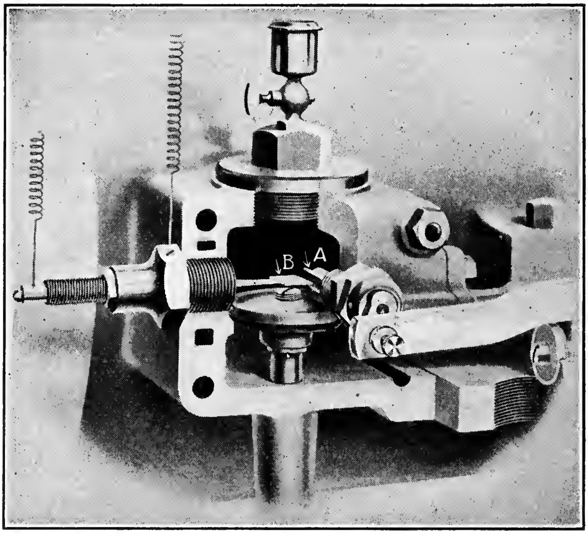


Fig. 189.—Wipe spark igniter.

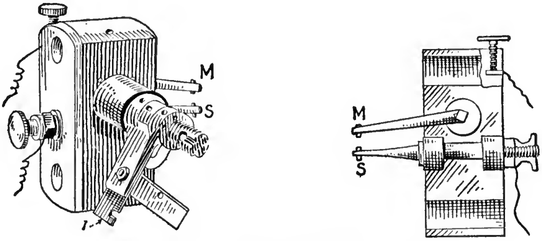


Fig. 190.—Hammer-break igniter.

Fig. 190 illustrates the hammer-break igniter. *M* is the movable and *S* the stationary insulated electrode. The points are rapidly separated by a sort of hammer blow furnished by the action of the springs on the end of the movable electrode. The hammer-break igniter is more commonly used than the wipe spark on account of the easier adjustment and less wear of the contact points.

The Jump Spark System of Ignition.—The principle of the jump spark system is illustrated in Fig. 191. *A* is a spark plug, the points *E* and *F* of which project into the cylinder. These points are stationary, are insulated from each other, and are separated by an air gap of about $\frac{1}{32}$ inch. When the switch *W* is closed, the current from the battery *B* flows through the timer *T*, which completes the circuit at the proper time through the induction coil *I*. The induced high voltage current produces a spark at the gap of the spark plug, igniting the explosive mixture in the cylinder.

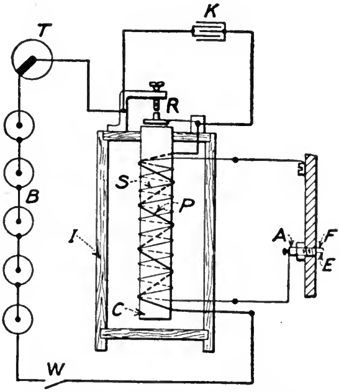


Fig. 191.—Jump-spark ignition system.

The induction coil *I*, Fig. 191, differs from the inductance coil used in connection with the make-and-break system of ignition (Fig. 188), in that there are two layers of insulated copper wire wound around the soft wire core of the induction coil, whereas in the inductance coil there is only one winding, the primary. The winding immediately surrounding the core consists of several turns of fairly large insulated copper wire and is known as the primary winding. The outside winding is known as the secondary and consists of a large number of turns of very fine insulated wire. It is wound over the primary without any metallic connections. In some cases a common end or terminal is used, in which case this terminal is grounded thereby eliminating one ground wire.

The primary current must be broken or interrupted in order to induce a current in the secondary winding. In the common form of induction coil this is done by means of vibrator, sometimes called an interrupter. The function of the vibrator is to break the primary circuit with great rapidity, thereby inducing a high voltage alternating current in the secondary winding.

This results in a series of sparks at the air gap of the spark plug.

An electric condenser *K* is made use of to prevent the burning of the vibrator points. It consists of alternate layers of tin-foil and some insulating material such as paraffined paper and is connected across the vibrator points. In addition to preventing sparking at the vibrator points, the condenser absorbs the excess current at the primary winding and again gives it up at the proper time to increase the intensity of the spark.

The induction coil, consisting of all the parts mentioned, is usually placed in one box and the space between the parts is filled with some insulating material such as wax or paraffine, in order to protect the parts from moisture.

In some cases the primary circuit is broken by some mechanical means, thereby eliminating the vibrator. One vibrator, known as a master vibrator, is sometimes used to break the circuit for several coils. In either of the last two cases mentioned, the non-vibrator type of induction coil is used.

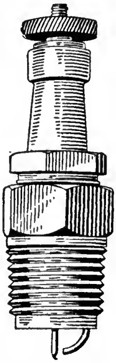


Fig. 192.—Spark plug.

The current from the battery *B* (Fig. 191) enters the primary circuit *P* through the timer *T* and the vibrator *R*. The other end of the primary is connected through a ground with the other terminal of the battery, thereby completing this circuit. As the current flows it magnetizes the soft iron core *C*. The magnetized core immediately attracts the steel spring of the vibrator and thereby breaks the primary circuit. The core *C* being of soft wire, it immediately loses its magnetism and the spring *R* is released ready again to complete the primary circuit. This vibrating action induces a high voltage current in the secondary winding *S*, one end of which is connected to a ground and the other to the center post of the spark plug. The circuit is then complete with the exception of an air gap of approximately $\frac{1}{32}$ inch at the spark plug points, across which the current jumps, producing a series of sparks which ignite the charge.

A spark plug, such as is illustrated in Fig. 192, is used with the jump spark system. It consists of two well insulated metallic points. The central point is connected to a binding post which receives the current from the secondary or high tension winding of the induction coil. The other point is about $1/32$ inch distant from the first and is separated from it by an air gap. The second point is grounded through the thread of the plug to the engine frame. The insulating materials used in the spark plugs are mica, porcelain, and stone. The plugs are well insulated except at the air gap.

Comparison of the Two Systems of Electric Ignition.—The jump spark system is much more simple mechanically, as it has no moving parts inside the cylinder. The make-and-break system is more simple electrically, requires less care in wiring, does not have to be insulated so carefully, and the spark is more certain. It is difficult to lubricate the many parts of the make-and-break system. The make-and-break system is usually used on stationary slow-speed engines and to some extent on tractors. The jump spark system is better adapted for high-speed and multiple cylinder engines than is the make-and-break, and is used on automobiles, tractors, trucks, small stationary engines, marine engines, and airplanes.

Source of Current for Make-and-break, and Jump-spark Systems.—The electric current for producing the spark in the make-and-break system may be obtained from a primary battery of dry or wet cells, from a storage battery, low voltage dynamo, or from a low tension magneto. The current for the jump-spark system may be obtained from any of the above sources or from a high tension magneto. In the latter case, the induction coil is a part of the magneto.

Either system requires a source with about six volts pressure. In case of a battery this may be obtained by connecting in series 4 to 8 dry cells, or 3 to 4 storage battery cells.

Electric Batteries.—Batteries are of two types—one type, called the primary battery, generates electrical current by means of direct chemical action between certain substances; another type, called a secondary battery, or storage battery, requires charging with electricity from some outside electrical source before it will generate electrical energy. The active materials in the primary battery when once exhausted cannot be brought back to generate electricity and must be renewed, while in the storage battery the active materials can be used over and over again.

The term battery is applied to two or more cells, whether primary or storage types, when they are connected together to increase the total amount of electrical energy delivered to a circuit.

Primary Batteries.—A primary cell (Fig. 193) consists essentially of a vessel containing some acid called the electrolyte, in which are immersed two solid conductors of electricity, called electrodes, one of which is more easily attacked by the acid than the other. A simple cell consists of a weak solution of sulphuric acid, as an electrolyte, a plate of zinc, which is easily decomposed by the sulphuric acid, and a plate of some other solid like copper or carbon which resists the action of sulphuric acid. If the plates of zinc and of copper are put side by side in a vessel containing sulphuric acid, and the circuit is completed by joining the two plates with a wire, chemical action will be set up within the vessel or cell, and a current of electricity will be generated.

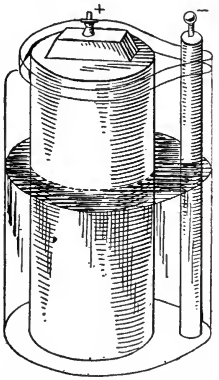


Fig. 193.—Wet primary cell.

The dry cell, which is used extensively at the present time on account of its portability, is a modification of the cell illustrated in Fig. 193. It has zinc for the negative electrode, carbon for the positive electrode, salamoniac and zinc chloride as the electrolyte for decomposing the zinc, and some oxidizing agent like manganese dioxide to eliminate polarization. The solution in the dry cell evaporates slowly, so that it will become worthless after a time, even if not used. Generally a dry cell in good condition will have a current strength of 15 to 25 amperes and should show a pressure of 1¼ to 1½ volts. A binding post is attached to the carbon and another one to the edge of the zinc cylinder.

Storage Batteries.—A storage battery consists of two sets of plates or electrodes known respectively as positive and negative, submerged in a liquid called the electrolyte. The plates are encased in a jar or container. This type of battery must be charged frequently with electricity, in order that it may continue to give out current to the external circuit. The storage battery does not store electricity. It stores energy in the form of chemical work. The electrical current produces chemical changes in the battery and these allow a current to flow in the opposite direction when the circuit is closed.

Storage batteries are used for gas-engine ignition and are preferred for this purpose to primary dry or wet batteries, on account of their greater capacity and more uniform voltage. Modern automobiles also employ storage batteries for starting, lighting, and ignition.

The capacity of a storage battery is measured in ampere-hours, determined by multiplying the current rate of discharge by the number of hours of discharge of which the battery is capable at that rate. As an illustration, a battery that will deliver 10 amperes for 8 hours has a capacity of 80 ampere-hours. The ampere-hour capacity of a storage battery is dependent upon the rate of discharge. Most manufacturers specify the rate of discharge for their particular make of storage batteries. If the rate of discharge is greater than the specified amount, the capacity of the battery is reduced. As an illustration, if a storage battery has a capacity of 80 ampere-hours, at the 10 ampere rate, it will have a greater ampere-hour capacity if discharged at a 5 ampere rate; that is, it will deliver a current of 5 amperes for more than 16 hours. The normal rate of discharge is the 8 hour period.

A storage battery can be charged from any direct current circuit, provided the voltage of the charging circuit is greater than that of the storage battery when fully charged. Before a storage battery is connected to the charging circuit its polarity should be carefully determined, and the positive and negative terminals of the battery connected to the positive and negative terminals, respectively, of the source. One good method of determining the polarity of the wires from the storage battery or source is to immerse them in salt water. Bubbles of gas will form more rapidly on the surface of the negative wire. Another test is that the negative wire will turn blue litmus paper red. Should the positive wire of the battery be connected to the negative wire of the source, the effect would be a discharge of the battery, and this being assisted by the incoming current, a reversal of action would take place. This is very injurious to the battery. It is not well to charge a battery at too rapid a rate, as this will raise its temperature and will cause buckling of the battery plates. It is well also to charge batteries at regular intervals.

Two types of storage batteries are used—the lead storage battery and the Edison. The Edison battery is also called the alkaline or nickel-iron battery.

The Lead Storage Battery.—The lead storage battery, Fig. 194, is the type used almost exclusively in connection with the modern motor propelled vehicles. In this battery both the positive and the negative plates are built upon lead grids. The perforations in the positive grid are filled with a lead compound (PbO_2) which may be distinguished by its brown color. The perforations in the negative grid are filled with spongy metallic lead which has a dull gray color. The positive plates are all united to a common positive terminal and the negative plates are all united to a common negative terminal.

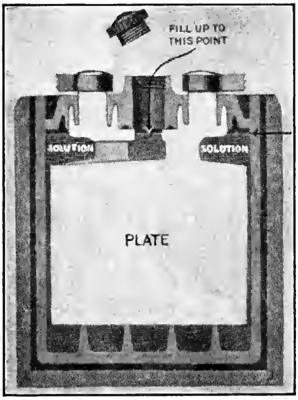


Fig. 194.—Cross-section through lead storage battery.

A lead storage cell, when fully charged, will show 2.2 to 2.5 volts on open circuit and about 2.15 volts when the circuit is closed. A lead storage battery should not be allowed to discharge to a voltage lower than 1.8 volts while giving its full rated current. For ignition purposes, 6 and 12 volt systems are employed.

For successful operation and long life, storage batteries should be tested frequently with a pocket volt meter for voltage, and with a hydrometer for the specific gravity of the electrolyte. The specific gravity of the electrolyte of a stationary battery should be 1.17 to 1.22 when the battery is fully charged. A portable battery should have a greater specific gravity, from 1.275 to 1.300 when fully charged. Pure distilled water must be added occasionally to the electrolyte to make up for the evaporation. The electrolyte should be ¼ to ½ inch above the plates.

The Edison or Nickel-iron Storage Battery.—The Edison storage battery, Fig. 195, consists of two sets of sheet-steel plates or grids, submerged in an electrolyte of caustic potash. The plates or grids support tubes and pockets containing the active materials. The active materials on the plates are nickel hydrate and a specially prepared black oxide of iron.

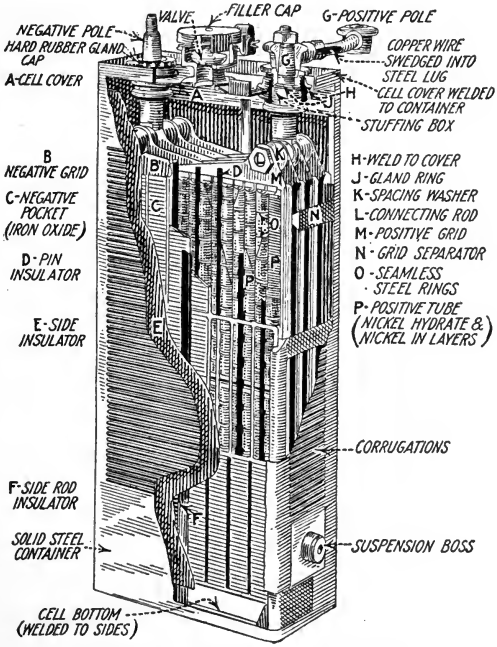


Fig. 195.—Edison storage battery.

The plates are held in a steel container which eliminates the danger of broken jars. Hard rubber insulation at the bottom and sides prevents electrical contact between plates and container.

Edison batteries do not have as high capacity when new as after some weeks of use. This is due to the improvement of conditions in the nickel electrode, brought about by regular charging and recharging.

The voltage of an Edison cell, when fully charged, is less than 2 volts, which is lower than in the case of the lead cell. This means that more Edison cells will be required for a given voltage than lead cells.

Ignition Dynamos.—An ignition dynamo is a miniature direct-current generator. It has electromagnets as field magnets and is usually of the iron-clad type. One form of ignition dynamo is shown in Fig. 196. In using an ignition dynamo the internal combustion engine must be started on batteries, as the speed developed when turning the engine by hand is insufficient to produce a spark of sufficient intensity by the dynamo. As soon as the engine speeds up, the battery current is thrown off and the spark is supplied by the ignition dynamo. Most ignition dynamos will supply a spark of sufficient intensity for a make-and-break system of ignition without an inductance coil.

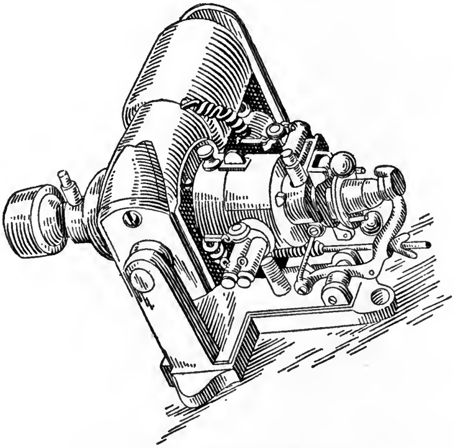


Fig. 196.—Ignition dynamo.

Magnetos.—The magneto differs from the ignition dynamo in that its magnetic fields are permanent magnets. For this reason it is unnecessary to run the magneto for any length of time in order to build up its field. Magentos can be run in any direction and at any speed. Magnetos can be classed under two general heads:

1. Low-tension magnetos which are used in place of batteries or of batteries and inductance coils.
2. High-tension magnetos which generate sufficient voltage to jump the gap of a spark plug.

Low-tension Magnetos.—The low-tension magneto may be of the direct-current type, in which case it differs from the ignition dynamo in that the magnetic field is a permanent magnet; or may be an alternating-current magneto. The alternating-current magnetos are generally used.

Fig. 197 represents a simple type of alternating-current low frequency magneto. It is used chiefly for the make-and-break system of ignition and takes the place of the battery and inductance coil.

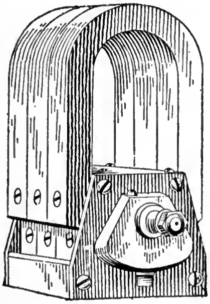


Fig. 197.—Low-tension magneto.

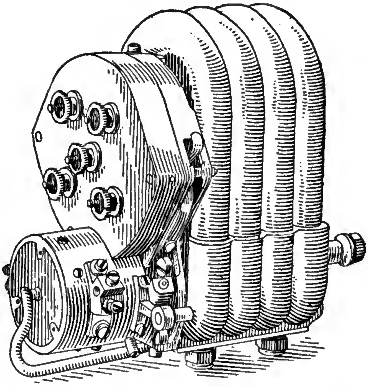


Fig. 198.—Low-tension magneto with circuit breaker and distributor.

The magneto illustrated in Fig. 198 is also a low-tension, alternating-current magneto, differing from the preceding one in that it has a circuit breaker and a distributor. This magneto can be used for a jump-spark ignition system when used with a non-vibrating induction coil.

The distributor is made use of in case of multi-cylinder engines. The function of the distributor is to send the current to the right cylinder at the proper time. The circuit breaker, or interrupter, takes the place of the vibrator in the induction coil and mechanically breaks the primary circuit thereby inducing a high voltage current in the secondary circuit. The distributor is timed with the circuit breaker and the circuit breaker is timed with the engine, so that the hottest spark takes place at the time of ignition.

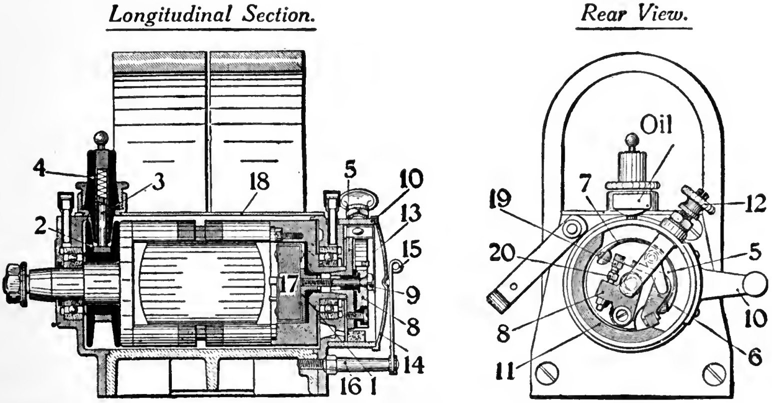
Inductor Type of Magneto.—In all of the magnetos previously mentioned, the armature carried the winding and has been the revolving or rotating part. In the inductor type of magneto the winding and the field magnets are stationary and the revolving part, which turns between the pole pieces, is made up of a steel shaft upon which are mounted laminated iron inductors. By laminated parts are meant those made up of punchings of sheet iron placed side by side.

In the inductor type of magneto, all moving wires, carbon brushes, and collector rings are eliminated. It is possible to have inductor type of magnetos in connection with any type of ignition on which magnetos are used. The oscillating magneto is one of the inductor type and is most commonly used with the make-and-break system of ignition. This magneto gets its name from the fact that the moving part does not revolve through a complete circle, but merely oscillates through a very few degrees. The rapid separation of the points is caused by strong springs attached to the arms situated near the end of the rotor shaft. As the spring snaps the inductor back the current is generated and at the same time the igniter points within the cylinder are very quickly separated, producing the spark.

High-tension Magnetos.—A high-tension magneto differs from a low-tension magneto in that it can generate a high voltage current without the aid of an induction coil. Fig. 199 illustrates a high-tension magneto all the parts of which are named. Both the primary and secondary windings are wound on the same core. In the armature type, both windings are on the armature and revolve with it, while in the inductor type both primary and secondary windings are on the stationary coil between the pole pieces.

In the armature type, the armature carries a primary winding of a few turns of fairly large insulated copper wire and a large number of turns of very fine insulated copper wire. The condenser is also carried in the armature. The interrupter or circuit breaker of a high-tension magneto is usually mounted on the end of the armature shaft and revolves with it. The high-tension current is taken from the armature by a brush and collector ring. The interrupter also acts as a timer and breaks the primary circuit at the proper time. This breaking of the primary circuit induces a high voltage current in the secondary exactly in the same manner as the vibrator did in the induction coil, previously discussed.

Due to the fact that the windings are revolving, there is a generative as well as an inductive effect. This generative effect prolongs the duration of the spark which would be of very short duration with the inductive effect alone. The cams must be so arranged that the primary is broken at approximately the time when the voltage is at a maximum, which is when the armature core is removed from the field.



1. Contact plate.
2. Slip ring with distributor segment.
3. Carbon.
4. Carbon holder.
5. Contact-breaker disc.
6. Bell-crank lever.
7. Bell-crank lever spring.
8. Contact piece.
9. Fastening screw for contact breaker.
10. Timing lever.
11. Steel segment.
12. Sheet-circuiting screw.
13. Flat spring for timing lever.
14. Brass end cap.
15. Flat spring.
16. Bolt for spring 15.
17. Condenser.
18. Dust cover.
19. Short platinum screw.
20. Long platinum screw

Fig. 199.—High-tension magneto.

A safety gap is provided in high-tension magnetos to protect the secondary winding. This is simply an air gap across which the current may jump in case of a break in the secondary winding. Without the safety gap the insulation of the secondary would be in danger of being punctured by the high voltage current in case of a break or loose connection.

If more than one cylinder is to be served, a high-tension magneto carries a distributor which distributes the current to the proper cylinder.

Fig. 200 illustrates a typical wiring diagram of a high-tension magneto of the armature type.

Timer and Distributor Systems.—With multiple cylinder engines a timer is often used in connection with vibrating induction coils. The function of the timer is to complete the primary circuit at the proper time for each cylinder thereby causing the vibrator to function resulting in a hot spark at the spark plug.

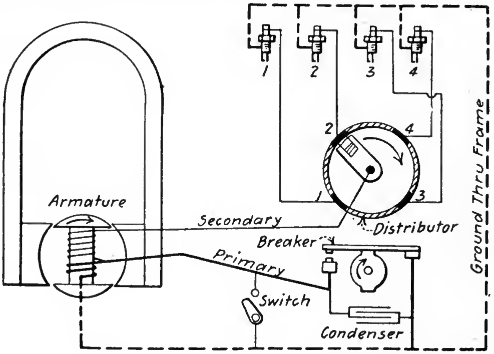


FIG. 200.—Wiring diagram for a high-tension magneto.

One type of timer, illustrated in Fig. 201, is used on a four-cylinder engine. *E* represents the segments in the housing *S*. These segments are electrically insulated from each other with fibre or some other insulating material. *R* is the revolving arm for closing the circuit at the proper time.

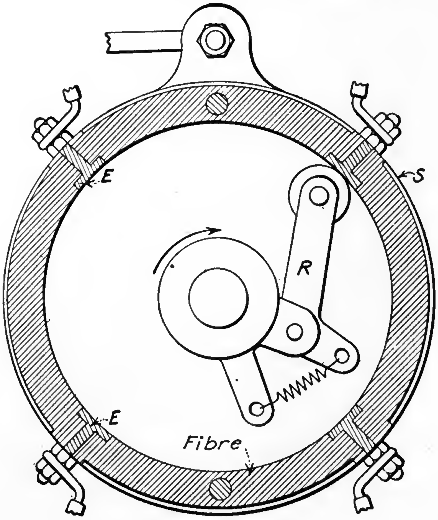


FIG. 201.—Timer.

The distributor system of ignition is very common practice on multiple cylinder high-speed engines. In this system the distributor and circuit breaker are mounted on one shaft. This shaft has projections or in some cases indentations equally spaced and corresponding to the number of cylinders to be served. These projections or indentations act as cams for interrupting the primary circuit. A condenser is usually placed across the breaker points to prevent sparking at the points. In connection with this system a non-vibrating induction coil is usually used. One end of the secondary is usually grounded, while the other leads to the center post of the distributor. The distributor then conducts the secondary to the proper cylinder at the proper time.

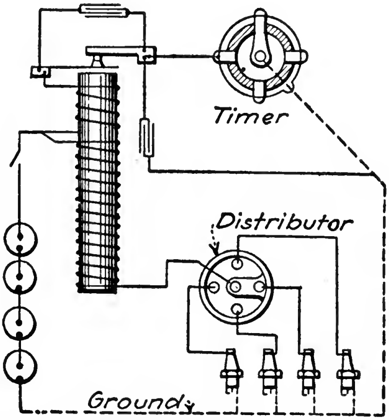


Fig. 202.—High-tension distributor system.

Fig. 202 represents a high-tension distributor system employing a timer and vibrating induction coil.

In most distributor systems a circuit breaker takes the place of both timer and vibrator so that a non-vibrating induction coil can be used.

Governors

Every internal combustion engine must be provided with a governor in order that its speed may be kept constant as the power developed by the engine varies. Stationary engines are usually mechanically regulated, the governor being operated by the speed variations of the engine. Motor vehicles are generally hand-governed, but are often equipped with a limit governor to prevent overspeeding. The speed regulation of internal combustion engines is accomplished by one of the following methods: hit-and-miss system, varying the quality of the mixture, varying the quantity of the mixture, varying the time of ignition, and combination systems.

Hit-and-miss Governing.—In this system the number of explosions is varied according to the load of the engine. When the engine is running at full load the explosions follow each other in regular order until the speed has increased enough above the normal to cause the governor to act, preventing the drawing in of the next charge, thus missing an explosion. This is followed by the slowing down of the engine, which causes the explosions to recur.

The hit-and-miss system can be carried out in several ways depending upon the valve gear of the engine.

In the case of small engines, where the inlet valve is operated automatically by the suction of the piston, the governor acts by keeping the exhaust valve open, thus preventing the spring-loaded inlet valve from opening.

When the inlet valve is mechanically operated from the valve gear shaft, the governor acts directly on the inlet valve by withdrawing a trigger, called a pick-blade, or a cam-roller in the valve actuating mechanism, thus preventing the admission of a new charge at light loads.

The hit-and-miss system can also be operated by keeping the fuel valve closed so that the engine draws in only air at light loads.

The governor proper in connection with the hit-and-miss system is usually some form of fly-ball governor.

The hit-and-miss system of governing is very simple and gives good fuel economy at variable loads. As the explosions in the engine cylinder do not occur at regular intervals, this system of governing necessitates the use of very heavy fly-wheels in order to keep the speed fluctuations within practical limits. The hit-and-miss system is satisfactory for small engines where close speed regulation is not essential, but is not practical in connection with engines which must operate at nearly constant speed.

Quality Governing.—In this system the number of explosions per minute and the quantity of the mixture admitted to the cylinder remain constant, but the quality of the mixture, that is, the ratio of fuel to air, is varied according to the load. This is accomplished either by the governor controlling a throttle or a cut-off valve in the gas supply pipe. The inlet valve which admits the mixture to the engine cylinder opens under all load conditions to its full lift, admitting to the cylinder a mixture of the same volume at different loads. The governor controls both the air and gas openings, increasing the air supply at light loads in the same proportion as the amount of gas is decreased.

This method of governing retains the same compression pressure at all loads, but the fuel economy decreases very rapidly as the load drops, as weak mixtures are difficult to ignite and are slow burning.

Quantity Governing.—In the quantity governing system the proportion of air to fuel remains constant, but the speed regulation is accomplished by altering the quantity of the charge admitted to the cylinder at variable loads. This system of governing can be carried out by the use of a butterfly valve under the control of the governor, which throttles the charge in a manner similar to the throttling steam engine. By another method, called the cut-off method, the inlet valve is held open only during a portion of the suction stroke, and is suddenly closed at a point determined by the governor and suitable to the load. The cut-off method of quantity governing is similar in its action to the governor in connection with automatic cut-off steam engines, such as the Corliss.

Combination Systems.—A combination of the hit-and-miss and the throttling regulating systems has been tried. The throttling constant quantity system is used for loads above one-half the rated load of the engine, whereas the hit-and-miss system is employed for loads below one-half. Another combination governor uses quality governing at heavy loads and quantity governing at light loads. These combination systems have been designed to utilize the advantages of the several systems, but are complicated and are used only in special cases.

MUFFLERS

An exhaust muffler is generally used to silence the noise incidental to the escape into the air of the exhaust gases from an internal combustion engine. In some installations mufflers are also used for the air intakes of large engines.

Exhaust mufflers vary greatly in design, but are intended to silence the exhaust noise by reducing the velocity of the exhaust gases to a minimum, without appreciably increasing the back pressure.

In some cases, the muffler is an enlarged exhaust pipe or a vessel of suitable volume to permit the gradual expansion of the exhaust gases. Some mufflers are provided with baffles and other obstructions to reduce the velocity of the exhaust gases. In other cases, sprays of water have been employed in connection with mufflers, to reduce the velocity of the gases by cooling. The use of water is effective, but should not be employed if the exhaust gases contain sulphur compounds.

A muffler should have sufficient volume in order to throw little back pressure on the engine, should be strong enough to stand the strain of an explosion, which may result from the presence of unburned gases in the exhaust, and should be constructed so that it can be readily taken apart for inspection, cleaning and repair.

The exhaust gases from an internal combustion engine should never be allowed to escape into a chimney or into a sewer, as an explosion due to the accumulation of unburned gases may occur at any time.

Problems

1. Examine some float feed carburetor and hand in report showing how these carburetors differ from those described in the text. Clear sketches, showing fundamental details of construction, should accompany report.

2. Examine some magneto and hand in a report which will illustrate and explain its construction.

3. Show by means of clear sketches the details of a hit-and-miss governor and also of a governor of the throttling type.

4. Examine the lubricators in use on various stationary internal combustion engines and report in which respects these differ from lubricators for steam engines.

5. Make clear sketches of mufflers suitable for small and for large stationary internal combustion engines.

CHAPTER XIV

GAS POWER PLANT TESTING

The testing of internal combustion engines operating upon gaseous or liquid fuels is similar to the testing of steam engines, at least in the more important details. The heat supplied to the engine by the fuel and the delivered power are the two main points to be investigated. Indicators cards may be used to determine the inner workings of the cylinder and in measuring the indicated horse power. The amount of heat absorbed by the jacket water can be determined by weighing the amount of water passing through the jacket and taking the temperature of the inlet and outlet water.

Measurement of Fuel Used.—When the fuel used is in a gaseous state, the volume used is usually measured by some form of gas meter. Most commercial meters give a fair degree of accuracy, but they should be calibrated under the conditions to which they are subjected during the test. Venturi meters (Chapter X) are used when the volume of the gas to be measured is large.

When liquid fuels are used the amount supplied the engine is best measured by means of small platform scales. One method consists in placing a supply tank or reservoir upon the scales, using a flexible connection from the tank to the carburetor. The difference in the weight of the fuel at the beginning and at the end of the test gives a direct measure of the quantity of fuel used. The flexible connection between the tank and engine is best made of flexible metallic tubing having no rubber insertions. Rubber tubing is acted upon by petroleum fuels and is soon destroyed.

Many internal combustion engines are equipped with an overflow type of carburetor, in which a constant quantity of fuel is maintained in the carburetor by supplying a larger quantity of fuel than is necessary, while the excess is drained through an overflow pipe. In this case the method of weighing the fuel is much the same as that just explained, with the exception that the fuel from the overflow is collected in a separate vessel and is either returned to the main fuel tank before the final weighing at the end of the test or is weighed separately and the amount deducted from the weight as determined from the main tank.

Instead of measuring the fuel by weighing, measurements by volume are sometimes used. In that case a cylindrical vessel of small diameter is equipped with a gage glass. The vessel is calibrated by filling the tank to various heighths and by determining the corresponding weight of fuel per inch of height. The fuel supplied to the engine during the test is then indirectly measured by noting the difference of the fuel level in inches and converting it into pounds from the calibration data. Such a method is not considered accurate because of the change of volume of the fuel with the change of temperature. For accurate results the method of direct weights should be used.

Heat Consumption of the Engine.—The heat consumption of the engine, or the heat supplied by the fuel, is found in the case of gaseous fuels by multiplying the heat of combustion of one cubic foot of the fuel, as determined by calorimeter test, by the volume of the gas consumed in cubic feet. For liquid fuels the heat consumption is equal to B.t.u. per pound of fuel multiplied by the weight of fuel used in pounds.

Brake Horsepower.—The brake horsepower, or the delivered horse power, of an internal combustion engine is usually measured by means of a Prony brake. Other types of dynamometers, as explained in the measurement of the delivered power of the steam engine (Chapter X), could also be used.

When a Prony brake is used the power is calculated by the formula:

$$\text{B.hp.} = \frac{2\pi lwn}{33000}$$

In which $\pi = 3.1416$

l = length of brake arm in feet.

w = net weight as measured by the scale upon which the brake arm rests.

n = number of revolutions per minute.

Indicated Horsepower.—The indicated horsepower of an internal combustion engine is measured in practically the same manner as in the case of steam engines, but with the following differences: Ordinary types of steam engine indicators are not well adapted to the testing of gas engines. The pressures exerted in the gas engine cylinder are usually higher than those common in steam engines and are more suddenly applied. In order to withstand these stresses the steam engine indicator would have to be equipped with a comparatively strong spring. The piston of the gas engine indicator is usually made ½ the area of that of the steam engine indicator piston and the springs are interchangeable. Thus a 100 pound steam indicator spring when used with a gas engine indicator would produce a one-inch vertical movement of the pencil for a pressure of 200 pounds.

In calculating the indicated horsepower, it must be remembered that the complete cycle is not produced at every revolution and it is the number of explosions rather than the number of revolutions that determines the horse power.

The formula for calculating the indicated horsepower becomes:

$$\text{I.hp.} = \frac{plae}{33{,}000}$$

In which

p = mean effective pressure in pounds per square inch as determined from the indicator card.
l = length of the engine stroke in feet.
a = area of the piston in square inches.
e = number of explosions per minute.

The Measurement of the Heat Absorbed by the Jacket Water. The heat absorbed by the jacket water is calculated by the formula:

$$W(t_2-t_1)$$

In which

W = the weight of water passing through the jacket in a unit of time.
t_2 = the temperature of water discharged from the jacket.
t_1 = the temperature of the inlet water to the jacket.

The weight of the jacket water is best measured by the use of one or more tanks placed upon platform scales. During the test these tanks are alternately filled, weighed, and emptied.

Duration of Test.—When the load upon a gas or oil engine is nearly constant, and can be maintained so for an appreciable period, the duration of the test need not be more than about one hour. When the load fluctuates, longer periods are necessary for accurate results.

Starting the Test.—Before starting a test upon a gas or oil engine sufficient time should be allowed for conditions to become constant. The engine should be operated at the prescribed load until all parts are thoroughly heated. At a certain predetermined time the test is started and the regular measurements and observations are made until the test is closed.

Gas Producer Testing.—To ascertain the efficiency of a gas producer the following data must be obtained: the quantity of fuel used, the amount of gas generated, the heat of combustion of the fuel, and the heat of combustion of the gas.

The heat of combustion of the fuel and of the gas can be determined by means of the calorimeters explained in Chapters II and XII respectively.

To determine the amount of fuel used, the length of the test should be such that the total consumption of the fuel should be at least ten times the weight of fuel contained in the producer during normal operation. Producer tests of short duration are inaccurate. The fuel used is weighed on platform scales.

The amount of gas generated is determined by means of a Venturi meter, Pitot tube, or some other gas meter of special design.

In a complete test the amount of power required for driving the fans and other auxiliaries is determined, as well as the amount of steam used and the final purity of the gas.

A. S. M. E. Code.—Complete and more detailed instruction concerning the testing of Gas Power Plants will be found in the *Rules for Conducting Performance Tests of Power Plant Apparatus*, published by the American Society of Mechanical Engineers.

Problems

1. Determine by test the amount of fuel used by an internal combustion engine per brake horsepower per hour.

2. Compare the heat consumption in B.t.u. of the following engines per brake horsepower per hour:

(*a*) Gasoline engine which delivers a brake horsepower per hour for one-tenth of a gallon of gasoline.

(*b*) Producer gas plant which consumes 1½ pounds of anthracite coal per B.hp.

(*c*) Diesel oil engine which consumes 0.47 pounds of crude oil per B.hp.

(*d*) Alcohol engine which consumes one pound of alcohol per B.hp.

3. Compile from the Power Test Code of the American Society of Mechanical Engineers a table suitable for taking data in connection with a complete test on a gas producer plant.

CHAPTER XV

LOCOMOTIVES

The Locomotive Compared with the Stationary Steam Power Plant.—On account of requirements which must be met in each case, the locomotive and the stationary steam power plant differ in construction. The stationary power plant has practically unlimited space available. The locomotive is limited in width by the gage of the track, and by the clearance required for station platforms and passing trains; it is restricted in height by the clearance of bridges and tunnels; the sharpness of the curves limit its length, and its weight is practically fixed by the strength of bridges and by the type of road bed. To develop the variable power demands to which locomotives are subjected, the boiler must contain ample heating surface and at the same time must occupy small space. The rate of combustion must be forced to the extreme, as the grate surface is limited in width by the allowable road clearance and in length by the distance a fireman can spread the coal. In stationary plants 10 to 20 pounds of coal are ordinarily burned per square foot of grate surface when operated with natural draft; in locomotive practice, by the use of artificial draft 150 pounds or more are usually burned per square foot of grate surface.

Space limitations on locomotives prohibit the use of fans or of high stacks for the production of draft, and an induced draft created by the exhaust steam must be used. This practice prevents the operation of the engine condensing and makes difficult the use of the exhaust steam in connection with feed water heaters.

The Essential Parts of a Locomotive.—The essential parts of a locomotive are illustrated in Fig. 203. The boiler (1) consists of a cylindrical shell, closed at its two ends by tube plates which are connected below the water level by numerous fire-tubes (3).

The furnace, or fire-box (2), is an extension of the boiler shell, the sides of which extend downward, forming a chamber surrounded at the top and at the bottom by water. The bottom of the fire-box is fitted with a grate (24) upon which the fuel is burned. Below the grate is an ash pan (28) which retains the ash until such a time as it may be removed. An opening at the back of the fire-box serves as a fire-door (23).

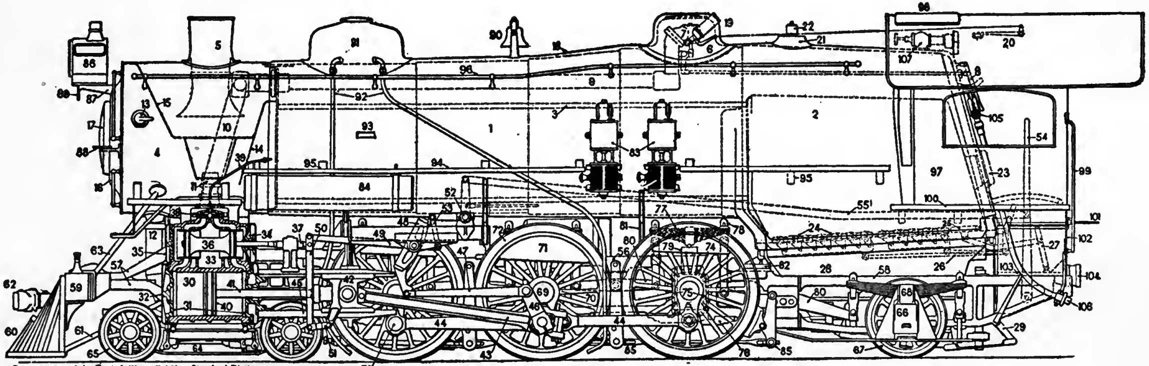
The furnace gases pass through the fire-tubes and enter the front-end or smoke box (4). In entering the smoke box, the gases are deflected downward by the diaphragm or deflector plate, thence through the spark-arrester netting (15), after which they mingle with the exhaust steam entering the smoke box from the exhaust pipe (11), and pass out the stack (5). Accumulation of cinders is removed from the smoke box through the spark chute (12), cleaning tools being inserted through the spark cleaning hole (13). Access to the smoke box is made through the door (17), or the entire smoke box cover (16) may be removed.

Steam from the boiler enters the steam dome (6) from which it passes to the engine cylinder. The throttle lever (8), which controls the valve in the throttle chamber (7), is used to regulate the quantity of steam entering the cylinder.

The steam after passing through the throttle valve enters the dry pipe (9) which passes through the steam space and absorbs a certain amount of heat from the steam with which it is in contact. Upon reaching the smoke box the dry pipe terminates in a tee from which two steam pipes (10) are used to direct the steam into the two cylinders.

The two cylinders are on the opposite sides of the locomotive and the cranks are separated 90 degrees. Considering only one cylinder, the steam enters through the valve (36) and after performing its function it passes through the exhaust pipe (11) and is further utilized in creating the draft. When the engine is running the exhaust causes a constant movement of air through the furnace and tubes.

The reversing of the engine, as illustrated in Fig. 203, is accomplished by the use of the Walschaert valve gear (see Chapter V). The reversing lever (54) is located in the engine cab. The reach rod (55) connects the radius rod (49), thus giving a means for controlling the position of the link block with respect to the link (48) and thereby controlling the position of the valves and the direction of the engine. The motion of the link is obtained from



By permission of the Funk & Wagnalls' New Standard Dictionary.

FIG. 203.—Parts of a locomotive.

Guide for Parts of a Locomotive Fig. 203.

1 Boiler.
2 Firebox.
3 Fire tube.
4 Smoke box.
5 Smoke stack.
6 Dome.
7 Throttle chamber.
8 Throttle lever.
9 Dry pipe.
10 Steam pipe.
11 Exhaust pipe.
12 Spark chute.
13 Spark cleaning hole cap.
14 Diaphragm or deflector plate.
15 Spark-arrester netting.
16 Smoke box front.
17 Smoke box door.
18 Boiler lagging jacket.
19 Whistle.
20 Whistle lever.
21 Safety valve dome.
22 Safety valve.
23 Fire door.
24 Shaking grates.
25 Drop grates.
26 Shaking grate rod.
27 Drop grate lever.
28 Ash pan.
29 Ash pan dump bell crank.
30 Cylinder.
31 Cylinder heads.
32 Cylinder head casing.
33 Valve chamber.
34 Valve chamber head.
35 Valve chamber head casing.
36 Valve (piston).
37 Valve stem.
38 By-pass valve.
39 Oil pipe.
40 Piston.
41 Piston rod.
42 Crosshead.
43 Main rod.
44 Side rod.
45 Guides.
46 Eccentric crank arm.
47 Eccentric rod.
48 Link.
49 Radius rod.
50 Lap and lead lever.
51 Lap and lead lever connector.
52 Lift shaft.
53 Radius rod hanger.
54 Reverse lever.
55 Reach rod.
56 Main frame.
57 Front frames.
58 Rear frame.
59 Front bumper.
60 Pilot.
61 Pilot brace.
62 Coupler.
63 Smoke box bumper brace.
64 Front truck pedestal tie bar.
65 Truck wheel.
66 Trailer truck oil box.
67 Trailer wheel.
68 Trailer truck spring.
69 Driving axle.
70 Driving wheel center.
71 Driving wheel counter-balance.
72 Driving wheel tire.
73 Crank pin.
74 Driving box.
75 Driving box shoes.
76 Frame pedestal brace.
77 Driving spring.
78 Driving spring hanger.
79 Driving spring saddle.
80 Driver equalizer.
81 Expansion plate.
82 Firebox expansion brace.
83 Air pumps.
84 Main reservoir.
85 Driver brakes.
86 Headlight.
87 Headlight bracket.
88 Step.
89 Number plate.
90 Bell.
91 Sandbox.
92 Sand pipes.
93 Step.
94 Running board.
95 Running board bracket.
96 Hand-rail.
97 Cab.
98 Cab ventilator.
99 Cab hand hold.
100 Cab floor.
101 Apron.
102 Cab bracket.
103 Deck plate.
104 Back chafing plate.
105 Injector.
106 Supply pipe.
107 Steam turret.

the eccentric crank arm (46) and the additional motion from the lap and lead lever (50), as shown in the illustration.

The injector (105) admits water to the boiler. Sand stored in the box (91) is delivered to the rails through the sand pipes (92) when it is necessary to increase the adhesion of the drivers. Air pumps (83) deliver air to the braking system, while such parts as the bell (90), whistle (19), safety valve (22), and the head light (86), need no explanation.

Early History of the Locomotive.—Locomotives, if they may be designated by such names, were built prior to 1825, although in that year George Stephenson is credited with the first locomotive. Stephenson's "Rocket" was of foreign make, had cylinders 8 in. by 16½ in., weight about 4 tons, and was capable of making 29 miles per hour.

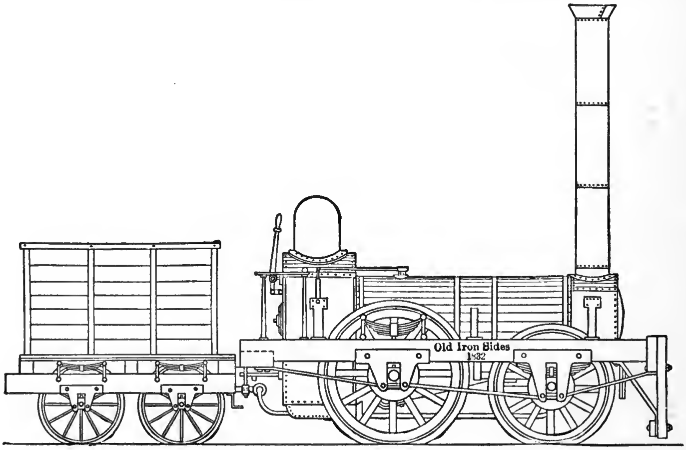


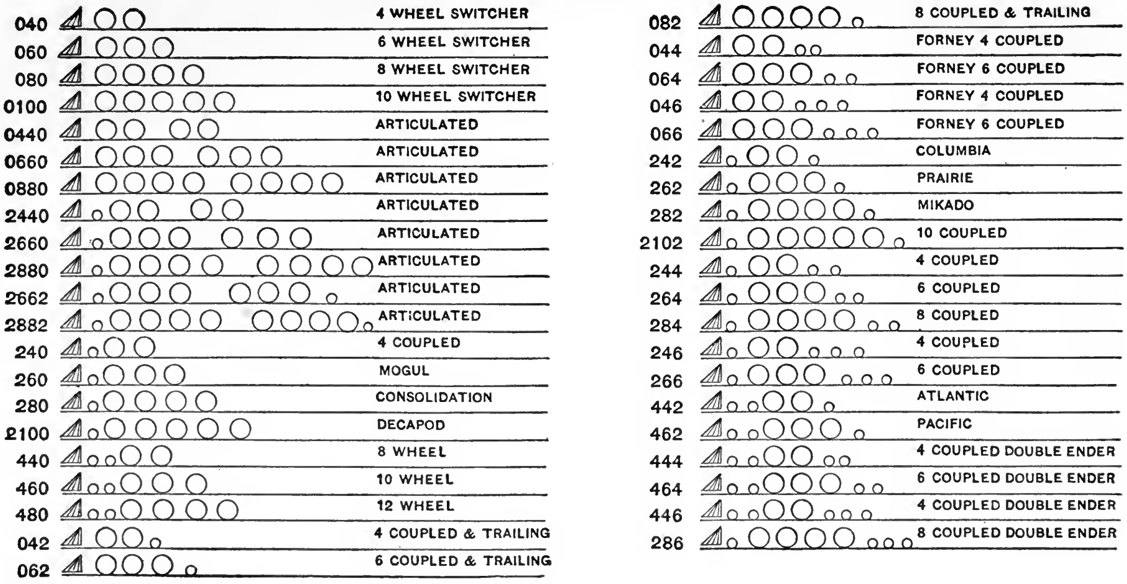
Fig. 204.—The locomotive of 1832.

In the United States "The Old Ironsides," built in 1832 was one of the first locomotives. As illustrated in Fig. 204, this was a four-wheeled machine; it weighed about 5 tons and was capable of operating at a speed of about 30 miles per hour.

The modern locomotive is a development of the above types. Its improvements paralleled the practice in steam-power engineering.

Classification of the Locomotive.—Several methods for the classification of locomotives are in general use. One method

TABLE 8.—CLASSIFICATION OF LOCOMOTIVES



040	4 WHEEL SWITCHER
060	6 WHEEL SWITCHER
080	8 WHEEL SWITCHER
0100	10 WHEEL SWITCHER
0440	ARTICULATED
0660	ARTICULATED
0880	ARTICULATED
2440	ARTICULATED
2660	ARTICULATED
2880	ARTICULATED
2662	ARTICULATED
2882	ARTICULATED
240	4 COUPLED
260	MOGUL
280	CONSOLIDATION
2100	DECAPOD
440	8 WHEEL
460	10 WHEEL
480	12 WHEEL
042	4 COUPLED & TRAILING
062	6 COUPLED & TRAILING
082	8 COUPLED & TRAILING
044	FORNEY 4 COUPLED
064	FORNEY 6 COUPLED
046	FORNEY 4 COUPLED
066	FORNEY 6 COUPLED
242	COLUMBIA
262	PRAIRIE
282	MIKADO
2102	10 COUPLED
244	4 COUPLED
264	6 COUPLED
284	8 COUPLED
246	4 COUPLED
266	6 COUPLED
442	ATLANTIC
462	PACIFIC
444	4 COUPLED DOUBLE ENDER
464	6 COUPLED DOUBLE ENDER
446	4 COUPLED DOUBLE ENDER
286	8 COUPLED DOUBLE ENDER

quite commonly used is based upon the wheel arrangement. This system indicates the number of truck, driving, and trailer wheels. Thus a 262 type would signify a machine having a two-wheeled front truck, 6 drivers, and a two-wheeled trailing truck. Table 8 gives the wheel arrangement, the designating name, and the numerical symbol of the various types of locomotives.

The Development of the Locomotive.—The development of the locomotive to its present state has resulted from the demands for machines of larger haulage capacity. The greatest difficulty found was in securing the larger boiler and grate areas which were necessary. The method by which these features were met is best illustrated by considering those types of locomotives which were especially designed for passenger traffic.

The American type, or the eight wheel, 440, was once considered the standard locomotive for passenger service, while at the present time its use is confined to light service.

The Atlantic type, 442, was developed from the American type, and in general the difference between the two types is the addition of a trailing truck. By this design the boiler-heating surface could be enlarged, while the use of the trailing truck rather than another set of drivers made space for the necessary additional fire-box capacity.

The Pacific type, 462, is the development of the Atlantic type using the same general design. The insertion of an additional driver is to distribute the weight by not having it concentrated upon two drivers, thereby increasing the rail contact and the amount of adhesion.

The Mallet Articulated Compound.—The need for larger powered locomotives and the limiting conditions to which the locomotive in its construction is subjected leaves practically but one course to follow if any increase in capacity is to be made and that is by increasing the number of drivers or the length of the engine. To increase the length and maintain a rigid type was out of the question on account of the difficulties and dangers in rounding curves.

The articulated compound locomotive, illustrated in Fig. 205, has been designed to meet the above conditions. This type consists of two sets of engines under one boiler. The rear set is fixed rigidly to the boiler while the front set supports the overhanging end of the boiler and is capable of adjusting itself to the alignment of the road. The two sets of engines are hinged together and exhaust pipes from one set of cylinders to the other are made flexible by ball and socket joints. The steam from the boiler enters the high pressure cylinders and exhausts into the low pressure cylinders, which are located on the front engine, from which the steam exhausts as is the case in other types.

The most powerful locomotives are of the articulated type. While little used at the present time in passenger service, they have been very satisfactory in heavy freight service especially on roads having heavy gradients combined with sharp curves.

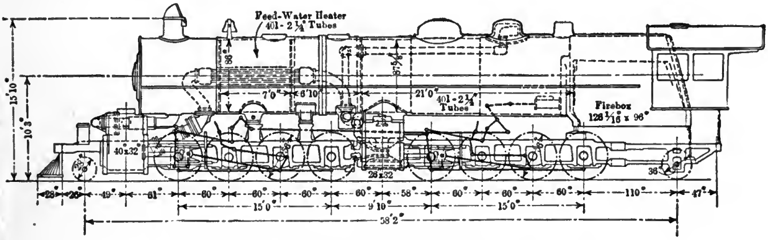


Fig. 205.—Articulated compound locomotive.

Locomotive Superheaters.—Two types of superheaters are used in locomotive practice: one receives its heat wholly from the gases in the smoke box, the other receives part of its heat from the smoke box, but the greater amount of heat is derived from superheater elements extending into the tubes.

The smoke box type is constructed wholly within the smoke box, requiring little or no change in the usual boiler arrangement, but has the disadvantage of being limited to low degrees of superheat. It consists of two small cast steel drums connected to each of the steam pipes, while numerous small tubes complete the path of the steam. The steam entering the upper drum passes through the tubes and absorbs heat from the flue gases which surround them.

One type of locomotive superheater is illustrated in Fig. 206. As usually constructed this superheater consists of a box or header *A* located in the smoke box to which are attached numerous superheating elements. These elements are constructed of seamless steel tubing and return bends, and are located in large fire-tubes *C* through which the furnace gases pass. The steam is thus made to pass through a superheating element before entering the cylinder. The flow of gases over the superheater surface is controlled by a damper *D* which is operated by the cylinder *E*. When the engine throttle is closed the damper is similarly closed, thus protecting the superheater tube. When the throttle is opened and steam is passing through the superheater, the damper is automatically opened.

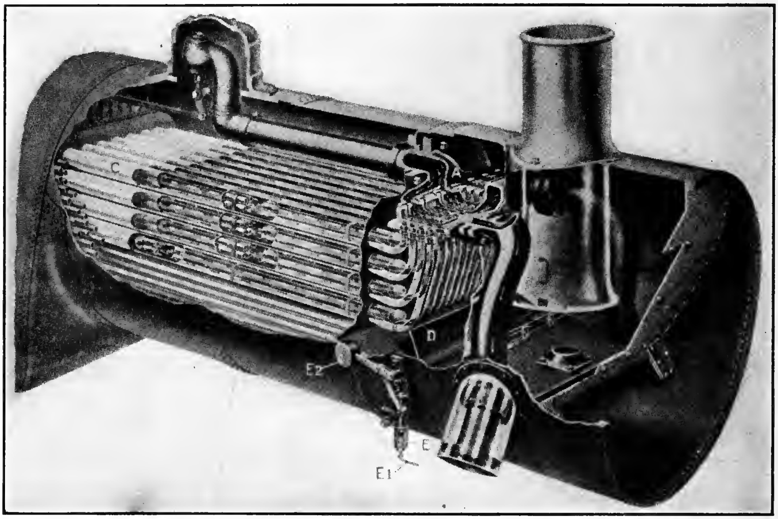


Fig. 206.—Locomotive superheater.

Locomotive Stokers.—Many different designs of stokers have been applied to locomotives. The chief advantage in the use of a mechanical stoker lies in the facility for the burning of a greater amount of coal and in the possibility of using cheaper fuels than is possible with hand firing.

Fig. 207 illustrates one type of locomotive stoker suitable for nut and slack coal. It consists of a screw conveyor placed under the floor of the tender and three distributing nozzles for spraying the coal over the fire.

Coal from the tender passes first through regulating screens, thence by a screw conveyor to the engine cab, and is finally delivered to the distributing nozzles from which it is fed to the furnace by means of a steam blast. Of the three distributing nozzles shown the central one utilizes the fine coal and feeds the center of the furnace. The remaining two are supplied with coarser coal and feed the two sides of the furnace.

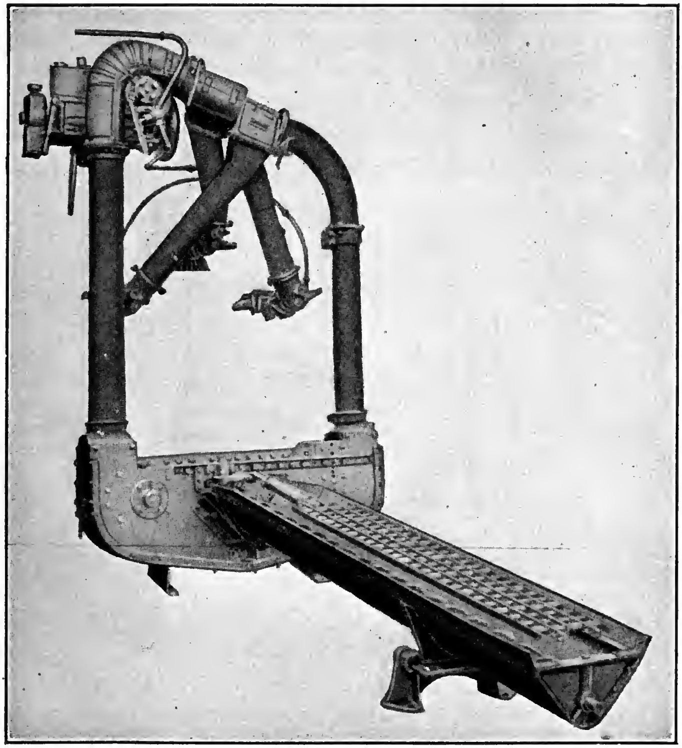


Fig. 207.—Locomotive stoker.

Draft Appliances.—A typical front-end is illustrated in Fig. 208. The exhaust steam from the cylinders passes through the exhaust ports into the exhaust pipe *E*, which terminates in a restricted area or exhaust tip. This arrangement regulates the velocity of the exhaust and the intensity of the draft. A small opening creates an intense draft, but at the same time raises the back pressure in the cylinder. The nozzle is arranged so that sufficient draft is obtained and the back pressure in the cylinders is as low as possible.

The stack extension or "Petticoat Pipe," *P*, is used when the exhaust nozzle is low. This is used as an additional channel to conduct the steam which, if not used, would fill the smoke-box, thus destroying the draft. The diaphragm *D* begins above the top row of tubes and terminates in a movable slide *S*, which may be raised or lowered to meet varying conditions. The diaphragm acts first to deflect the solid particles in the gases downward and second as a draft regulating device. Without the diaphragm the upper rows of tubes would be greatly affected by the exhaust. This would produce uneven burning of the fuel over the surface of the grate. By regulating the diaphragm the draft can be made uniform over the entire grate surface.

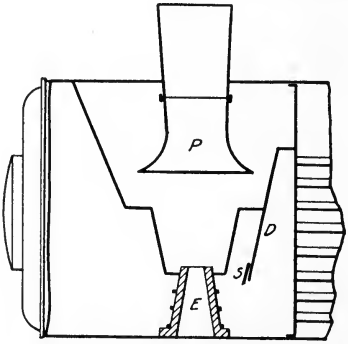


Fig. 208.—Locomotive front end.

Injectors.—The injector as a means of introducing feed water into a boiler is seldom used in stationary power plant practice. It is the general impression that the injector is not as reliable as the reciprocating pump and in addition cannot pump hot water. Its chief advantage is due to the small space it occupies and this fact makes it practical for use on locomotives, where space economy is important. To overcome the possibilities of failure to operate, locomotives are equipped with two injectors. If one injector becomes inoperative the other may be relied upon.

Air Brakes.—One of the first types of air braking systems was what was generally known as the Straight Air Brake. This consisted of a steam driven air pump located on the engine, a reservoir

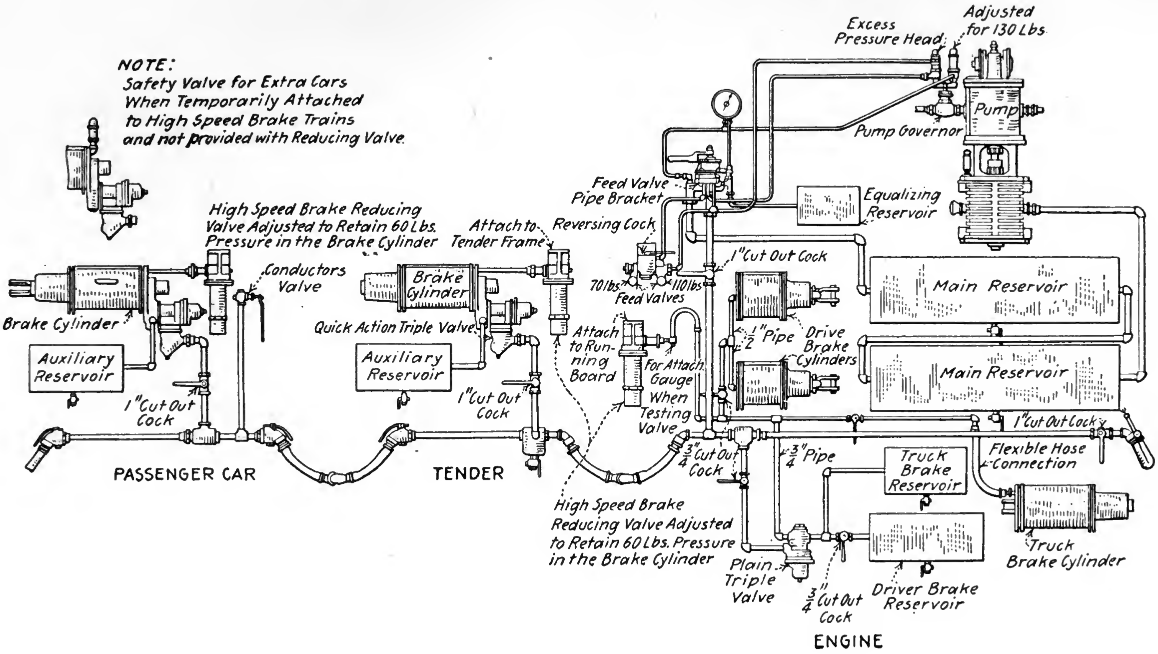


FIG. 209.—Automatic air brake system.

in which compressed air was stored, a pipe line extending throughout the length of the train, each car being connected by flexible hose couplings, and a brake cylinder on each car the piston of which was directly connected to the brake levers. The engineer's valve could admit air to the piping and thence to the cylinder causing the brakes to act, or could discharge the air from the braking system or train line, thus releasing the brakes.

Experience demonstrated that the use of the straight air brake system is dangerous when used on trains. The hose connection between cars often broke resulting in the loss of the braking effect throughout the entire train. When the train would brake apart the rear part often overtook that of the front with the possibility of a serious collision and damage. It was found necessary to have an automatic system and this led to the introduction of the indirect or automatic system which is still used.

The automatic system operates by decreasing the air pressure in the train line rather than by increasing it as in the case of the direct air system. A diagrammatic layout of an automatic system is illustrated in Fig. 209. A compressor delivers air to a main reservoir which is connected through the engineers valve to the train line. Under each car is another reservoir, termed the auxiliary reservoir, a brake cylinder and triple valve controlling air to and from the brake cylinder.

When the engine is coupled to the train, air is admitted to the train line, passes through the triple valve, and enters the auxiliary reservoir. When air is released from the train line, the lowering in pressure causes the triple valve to operate permitting the air in the auxiliary reservior to be transferred to the brake cylinder, thus the brakes are applied. In this system if a coupling hose should burst or the train part, the brakes would be set because of the lowering of the pressure in the train line.

Problems

1. In which respects does the locomotive power plant differ from the ordinary stationary steam power plant?

2. Ascertain what reversing mechanism is used on the locomotives passing through your city.

3. Compare the air-brake system used on electric street cars in your city with the automatic air brakes as used on locomotives.

CHAPTER XVI

AUTOMOBILES, TRUCKS AND TRACTORS

AUTOMOBILES

Types of Automobiles.—Automobiles are propelled by internal combustion engines, by steam engines, or by electric motors with current secured from storage batteries.

At the present time a very large majority of automobiles are driven by internal combustion engines using gasoline as fuel. The gasoline automobiles possess the following advantages: they are manufactured in many different types and designs, can be secured at a wide range of prices, are more economical than other types, and are usually provided with a fuel storage of sufficient capacity to propel the car several hundred miles. The disadvantages of the gasoline automobile are that it is not self-starting, lacks over-load capacity, and must be built with a complicated system of gears for speed changing and for reversing.

The automobile propelled by a steam engine is very flexible, is easily controlled, and has a very large range of power. To offset these advantages, the steam automobile requires considerable time to start after a long stop, as steam must be generated in the automobile boiler before the engine will start. This fault is being greatly remedied in some of the recent steam automobiles, but all steam automobiles require considerable skill in operation, as constant attention must be given to the fuel and water supply.

The electric automobile is also very flexible, operates more quietly than other types, is clean, and is easy to start and to control. The greatest disadvantage of the electric car is that it can run only for short distances without recharging its storage batteries. The use of the electric automobile is limited mainly to cities where facilities are available for charging storage batteries. Electric cars are also expensive to operate.

As steam and electric automobiles are not generally used, this chapter will deal only with the gasoline automobile.

Essential Parts of a Gasoline Automobile.—The essential parts of a gasoline automobile are:

1. A power plant, which consists of an internal combustion engine and its auxiliaries, such as the fuel system, carburetor, ignition system, and cooling and lubricating systems. In some cars this also includes the starting equipment.
2. Friction clutch, for disengaging the engine from the propelling mechanism.
3. Transmission mechanism for speed changing and reversing.
4. Differential gear, the purpose of which is to allow one drive wheel to revolve independently of the other, this being necessary when turning corners.
5. Front and rear axles.
6. The frame for supporting the power plant, the transmission system, and the body of the car. Interposed between the body and the axles are the springs, which are built up from a number of leaves.
7. Control system, which includes the steering mechanism, hand levers and foot-pedals, means for controlling the spark position, the carburetor throttle, the clutch, the transmission gearing, and the brakes.
8. Wheels, tires, lights, alarm, body, top, fenders, dash, running board, wind shield, and speedometer.

The term chassis is applied to the car with the body and accessories removed.

Automobile Motors.—Modern automobiles use four, six, eight, or twelve-cylinder motors. The motors are all of the vertical type and operate on the Otto four-stroke cycle. The engine is mounted in the front end of the car for accessibility, and also for the purpose of more evenly distributing the weight of the car. Multi-cylinder motors permit of easier starting, operate more smoothly, run with less vibration, and have a wider range of power. Four and six-cylinder engines have all cylinders in one row and located on one side of the crankshaft. Eight-cylinder engines have their cylinders V-type in two rows with the rows set at an angle of 90 degrees. Twelve-cylinder engines are of the V-type and have two rows of cylinders set at an angle of 60 degrees.

The cylinders may be cast singly or en-bloc; the en-bloc construction means that several cylinders are cast in one piece. The single-cylinder casting is light in weight and is easily replaced. The en-bloc motor is more rigid, occupies less space and is the more commonly used.

Cooling of Automobile Motors.—Automobile motors are generally water-cooled and are provided with radiators for the purpose of cooling the water after it has absorbed heat from the cylinder walls. Either the thermosyphon or the forced water circulation system is used.

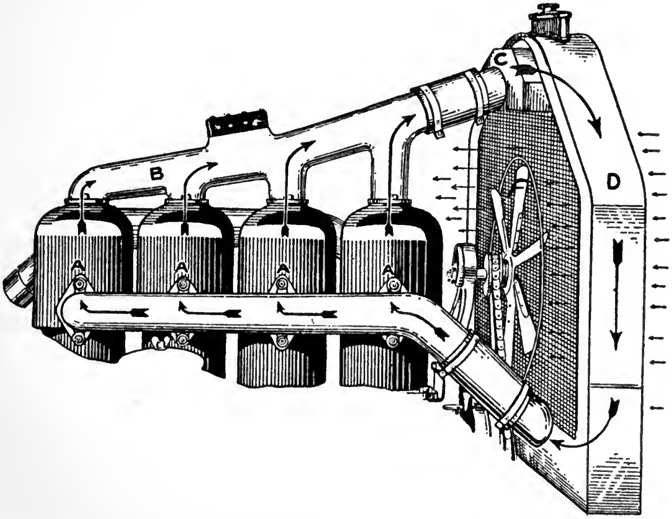


Fig. 210.—Thermo-syphon water-circulation system.

The thermo-syphon system (Fig. 210) depends upon the fact that water rises when heated. This system does not require a pump to circulate the water. The water enters the cylinder jackets at *A* (Fig. 210). Upon becoming heated by the explosions going on within the cylinder of the engine, the water rises to the tops of the cylinder jackets, entering the pipe *B* and passing into the radiator at *C* where it is brought into contact with the radiator cooling surfaces. On being cooled, the water becomes heavier and sinks to the bottom of the cooling system, to enter the cylinder once more and to repeat its circulation. The cooling action of the radiator is increased by the fan *F* which draws air through the radiator spaces.

The forced circulation cooling system differs from the thermosyphon system in that it has a circulating pump to aid in the circulation. The pump which is usually of the centrifugal type makes the circulation more positive. The course taken by the circulating water is exactly the same in both systems.

Some air-cooled automobile motors have proven very satisfactory. The cylinders of air-cooled motors are ribbed to increase the radiating surface and the circulation of the air is produced by means of a fan located in the motor fly wheel.

Lubrication.—Five methods are used for lubricating automobile motors:

1. The splash system. This system depends entirely upon dippers on the connecting rods to splash the oil to the various parts of the motor.

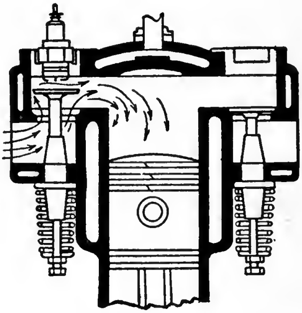


FIG. 211.—Motor with poppet valves.

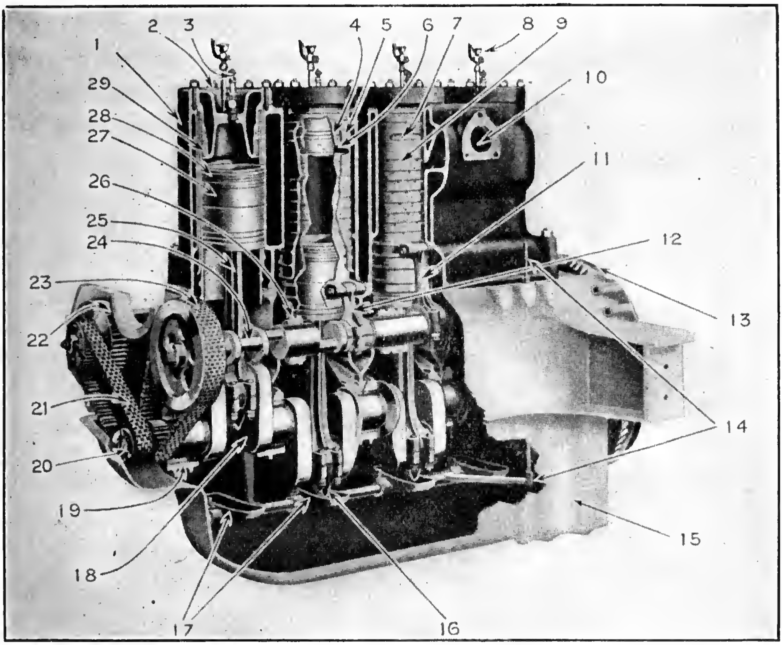
2. The circulating splash system. This differs from the straight splash method in that a pump at a low point in the crank case delivers the oil to troughs under the connecting rods. From these troughs the dippers splash the oil in the same manner as in the straight splash system.

3. The forced splash system. This system uses a pump to force the oil to the main bearings and to the troughs previously mentioned. Dippers on the connecting rods then splash the oil in the same manner as mentioned before. This system differs from the circulating splash in that the oil is forced to the main bearings.

4. The forced system. This system has a hollow or drilled crankshaft through which the oil is forced from the main bearings

to the connecting-rod bearings and is then splashed to the wrist pin and cylinder walls.

5. The full forced system. This system has tubes leading up along the connecting rods to the wrist pin. The oil is forced by the pump to the main bearings, thence through the crank-shaft to the connecting-rod bearings, thence through the tubes to the wrist pin, and through the hollow wrist pin to the cylinder walls. With a full-forced system a relief valve is provided to prevent the oil pressure from becoming excessive.



1. Cylinder.
2. Water-jacketed cylinder head.
3. Spark plug.
4. Inner sleeve.
5. Outer sleeve.
6–7. Port openings in sleeves.
8. Priming cup.
9. Oiling grooves in sleeves.
10. Port opening in cylinder.
11. Connecting-rod operating outer sleeve.
12. Connecting-rod operating inner sleeve.
13. Fly wheel.
14. Oil trough adjusting lever connected to throttle.
15. Lower part of crank case, containing oil pump, strainer and piping.
16. Oil scoop.
17. Adjustable oil troughs.
18. Crank shaft.
19. Crank-shaft bearing.
20. Starting clutch.
21. Silent chain drive for magneto shaft.
22. Silent chain driving sprocket for electric generator (on 4-cylinder models).
23. Silent chain drive for eccentric shaft.
24. Eccentric shaft.
25. Connecting rod.
26. Bearing for eccentric shaft.
27. Piston.
28. Piston rings.
29. Cylinder-head ring (junk ring).

Fig. 212.—Sectional view of Sterns-Knight four-cylinder motor.

The parts of the automobile motor which require lubrication are the main shaft bearings, crank-pin bearings, wrist-pin bearings, cam shaft bearings, timing gears, cams, cam lifter guides, cylinder walls, and other moving parts, such as yokes and ends of rods.

Automobile Valves.—The poppet type of valve, Fig. 211, is generally used on automobile motors. The sleeve valve type of motor (Fig. 212) is also used on certain designs of automobiles.

Poppet valve motors are built in several forms according to location of valves.

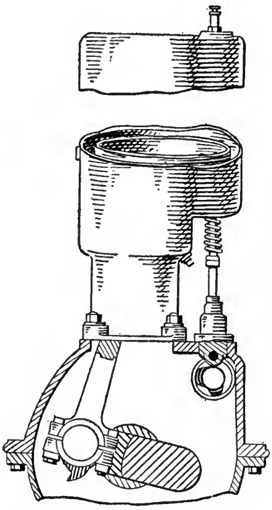


Fig. 213.—Ell-head cylinder.

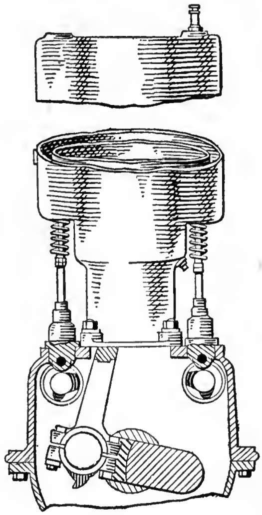


Fig. 214.—Tee-head cylinder.

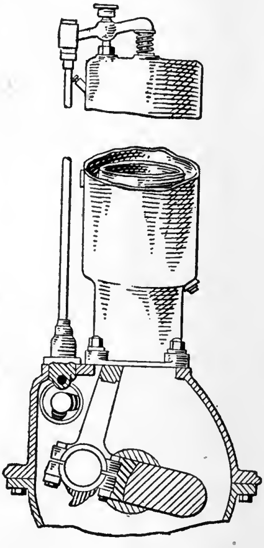


Fig. 215.—Valves-in-the-head cylinder.

1. The ell-head motor (Fig. 213) has both the intake and exhaust valves on one side of the cylinder.

2. The tee-head motor (Fig. 214) has the exhaust valves on one side of the cylinder and the intake valves on the other.

3. The valve-in-the-head or I-head motor (Fig. 215) has both intake and exhaust valves in the cylinder head.

4. The combination ell-head and valve-in-head, sometimes known as F-head, has the intake valve in the head and the exhaust valve on the side of the head.

Clutches.—The clutch is a device used for connecting the engine to, and disconnecting it from, the propelling gear of the car. Clutches depend upon the frictional adhesion between surfaces and are of two general types.

1. The cone clutch, illustrated in Fig. 216, consists of a leather-faced cone *C* which is pressed by the spring *S* against the inside of the tapered rim of a fly wheel *W*.

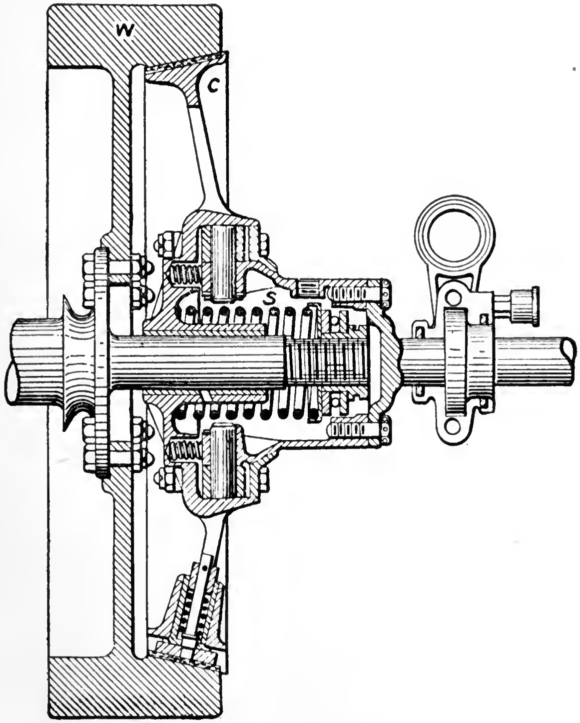


FIG. 216.—Cone clutch.

2. The multiple disk clutch (Fig. 217) depends for its action upon the friction between disks. Alternate disks are fastened to the driving and driven parts. The disks marked *A* are fastened to the engine shaft and those marked *B* connect with the mechanism to be driven. If the clutch runs in a bath of oil it is called a wet-disk clutch. A spring is employed to hold the disks in contact when the clutch is in action.

Transmissions.—The speed of an internal combustion engine and its direction of rotation cannot be varied to meet the requirements of an automobile. This necessitates the introduction of some form of mechanism for speed changing and also for reversing, in order that different speed ratios and reversal of direction can be secured between the engine and the drive axle. The mechanism, which is used in speed changing and in reversing, is known as the transmission. The transmission is so constructed that the propelling ability of the motor is increased at the expense of the speed of the automobile. That is, the motor through the gear ratios of the transmission is able to pull a larger load at a lower speed than it could by direct drive.

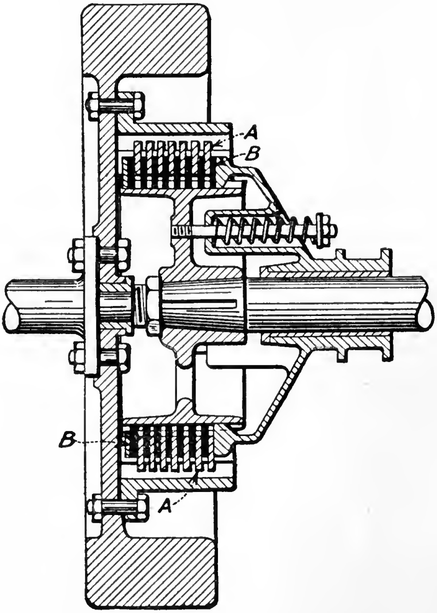


FIG. 217.—Multiple-disk clutch.

Only two types of transmissions are now extensively used, the selective sliding and the planetary type. The progressive sliding type and the friction drive are practially out of date.

Fig. 218 illustrates the selective sliding gear transmission system. The desired gear ratio can be obtained by means of this type of transmission without shifting through other positions. This system is most generally used.

In Fig. 218, *A* is the driving shaft, *B* the driven shaft. *S* and *L* are slides carrying yokes that move on the wheels *D* and *K*. All the wheels on the counter shaft are fast to the shaft. A lever is arranged for shifting either *S* or *L* and for allowing the various gears on the shaft *B* to mesh with those on the counter shaft. This system is usually arranged for three speeds forward and one speed reverse, but can be modified for any number of speeds forward and for reversing. For reversing an idler gear is provided between the driver and driven gears. High speed forward is usually direct drive. Some cars have transmissions which permit of a higher speed than the direct drive.

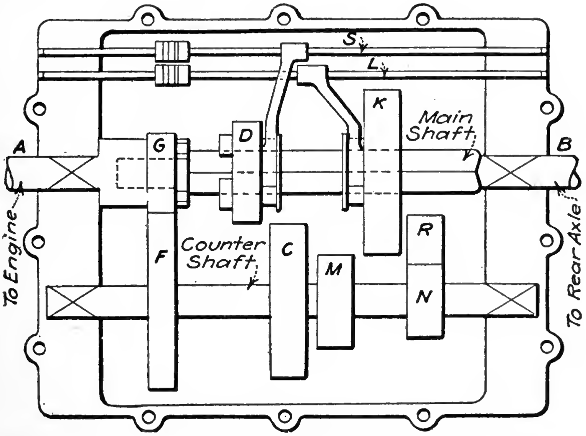


Fig. 218.—The selective sliding-gear transmission system.

In the planetary transmission system, speed changes do not depend upon the shifting of gears, but clutches or brakes are applied to hold certain wheels in position. The drive is positive and the gears are always in mesh. For high speeds this system is very well adapted, as the entire system is clamped solidly and revolves with the motor crank shaft as a single mass. As no gears are turning idly the entire system by its weight serves to steady the rotation of the motor at high speeds. The planetary system provides only two speeds forward and one reverse. It is inefficient in low speed and reverse, as much power is absorbed by friction in the gears and clutches. The use of the planetary system is limited to small automobiles.

Differentials for Automobiles.—Differential gears, sometimes called compensating gears, are provided to permit one wheel to turn faster than the other on turning corners or when meeting obstructions. The outside wheel in turning a corner has the greater distance to travel than has the inside wheel in the same length of time. In automobiles the differential is a part of the rear axle assembly. If two drive wheels were rigidly connected

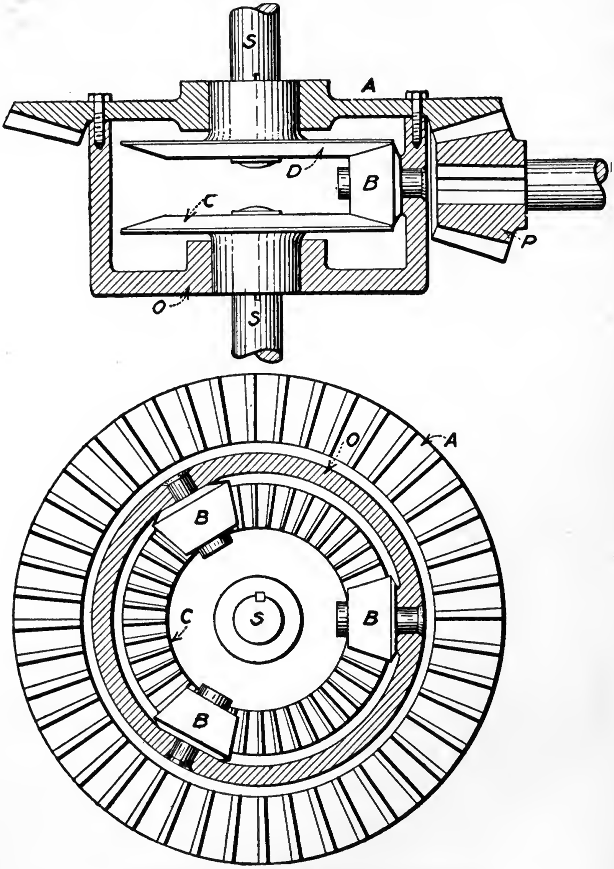


Fig. 219.—Bevel-gear differential.

without a differential it would be necessary for one wheel to skid or slip when turning a corner or when going over an obstruction, thereby throwing great strain on the parts and producing excessive wear on the tires.

The bevel gear differential (Fig. 219) is usually used on automobiles. The rear axle *S* (Fig. 219) is divided into two halves. Each half of the rear axle carries a drive wheel at its outer end and a bevel gear (*C* or *D*) at its inner end. The bevel gears *C* and *D* are connected by, from two to four, differential or compensating pinions (*B*, *B*, *B*) which are placed at equal distances apart around the circle. These bevel pinions (*B*, *B*, *B*) are capable of rotating loosely on radial studs, which are fastened at their outer ends to the casing or housing *O*. The gear *A* is made to turn loosely upon the hubs of the bevel gear *C* and *D*, but is made fast to the housing *O* by means of bolts or rivets. The power from the engine is transmitted to the housing *O* through the bevel gear pinion *P* which meshes with gear *A*. The housing transmits this power through the small bevel pinions (*B*, *B*, *B*) to the bevel gears *C* and *D*, which are connected to the rear or drive wheels. On a level road with both drive wheels rotating at the same speed, the housing *O*, with all the gears and pinions will revolve as one mass, and the small pinions (*B*, *B*, *B*) will remain stationary. The wheel which turns the more easily is always the one to turn. In turning a corner, in meeting an obstruction, in case one of the wheels slips, or if the drive wheel attached to the bevel gear *C* must turn slower than that attached to gear *D*, the differential pinions (*B*, *B*, *B*) will revolve on their axes. The bevel pinions (*B*, *B*, *B*) divide the torque between the two bevel gears *C*, *D*, thereby permitting the two drive wheels to run at different speeds.

Universal Joint.—Since the engine and the gearing are mounted on the frame of the automobile, while the driving wheels are connected to the frame by springs, automobiles must be provided with one or more flexible joints. The flexible joint is known as a universal joint and consists of two forked arms at the ends of shafts. These forked arms are joined by pins through their ends to a center member and are arranged so that the pin of one forked arm lies in the same plane, but at right angles to the pin of the other. This permits the lower end of the propeller shaft to move independently of the motion of the rear axle.

Front and Rear Axles.—The front axles are of a construction which permits the wheels to pivot near the hub. This reduces the tendency of the wheel to swing when striking an obstruction in the road. The steering knuckles are the part of the front axle assembly on which the wheels revolve. Steering arms are inserted in the knuckles and are connected together with an adjustable tie rod so that both knuckles turn simultaneously. A third arm, usually on the left hand knuckle, is connected to the steering gear by means of the steering connecting rod. Automobile front axles are drop forged with I-beam cross sections.

Rear axles for automobiles are live axles; that is, they turn with the wheels. They are divided into 3 types: the semi-floating, the three-quarter floating, and the full-floating. In the semi-floating type the entire load is carried on the axle. The bearing in a three-quarter floating is on the housing and the wheel is keyed to the axle; with this type it is not possible to remove the axle without also removing the wheel. When a full-floating axle is used the bearing is also on the axle housing and the entire weight is supported on the housing. With the full-floating type of rear axle the only strain on the axle is the torque in turning the wheel; as the axle is not fastened rigidly at either end it can be taken out without disturbing the wheel, by removing the hub flange.

Steering and Control Systems.—Automobiles are steered by means of a hand wheel which is located on top of the steering column. The steering gear operates on the front axle, through the steering connecting rod, and turns the knuckles and the front wheels. The steering column, besides the steering mechanism, usually contains several concentric tubes with connections to the alarm, the throttle control, and the spark control.

The spark and the carburetor throttle control levers are usually located on top of the steering wheel. On some cars they are located below the steering wheel.

Most modern cars are provided with two methods of throttle control, the hand throttle control on the steering column and a foot control, known as the accelerator.

The foot accelerator and the hand throttle control are so connected that the hand accelerator also works the foot accelerator, but the operation of the foot accelerator does not change the position of the hand control.

The control system includes a pedal for operating the friction clutch, one for operating the service brake, a lever for operating the emergency brake, and a lever for operating the speed changing and reversing gears of the transmission. In some makes of cars the service brake is operated by the clutch pedal and the emergency by the other foot pedal.

The Ford automobile is controlled by three foot pedals and by one hand lever. The pedals operate the clutch, the reverse, and the service brake. The hand lever operates the clutch and the emergency brake.

Brakes.—Automobile tires being made of rubber, the brakes are not applied to the wheel tires, but to metal drums which are fastened to the rear wheels. Two brakes are employed. One brake called the service brake, is operated by means of a foot pedal. The other brake, called the emergency brake, is usually operated by a hand lever and is intended for use only in case the service brake fails or in case a very strong braking action is required. The braking effect can be produced by expanding the brake band or shoe within the brake drum or by contracting the brake shoe around the outside of the brake drum. Automobiles usually have an external contracting brake for service, and an internal expanding brake for the emergency brake.

The brake bands are usually covered on the rubbing side with an asbestos preparation, which can be replaced when worn out.

Wheels and Tires.—Automobile wheels may be made of wood or of metal. On most cars the wooden wheels go with the standard equipment. Wire wheels are light in weight, but require care to keep all the spokes tight.

Automobiles use double pneumatic tires. The double pneumatic automobile tire consists of a rubber inner tube to be inflated and a casing, made up of rubber and canvas fabric, to protect the inner tube from wear. Two types of casings are used. They are known as the straight side and the clincher, depending upon the method of holding the casing in the rim.

Carburetors.—Automobile carburetors have been illustrated and described in Chapter XIII.

Ignition.—The jump spark electric ignition system is employed. Most modern automobiles employ a high-tension distributor system of ignition, using batteries as the source of current. Fig.

220 illustrates the wiring diagram of the Atwater Kent high-tension distributor system, which is operated with a storage battery, and includes the following:

1. A non-vibrator type of induction coil with primary winding, secondary winding, and electric condenser. This type of induction coil produces only a single spark as the circuit is made and broken only once. It is known as a unisparker.

2. A timer or contact-maker in the primary circuit. The timer is constructed so that the length of contact is independent of the engine speed.

3. A high-tension distributor with as many contact points as there are cylinders.

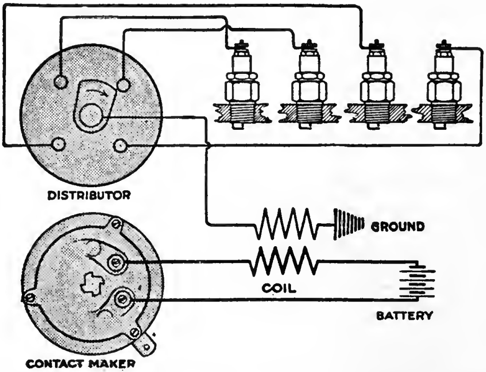


FIG. 220.—Wiring diagram of the Atwater Kent system.

4. A governor which automatically advances the spark within certain limits as the speed increases.

The automatic spark-advance mechanism, the contact maker, and the distributor are all carried on one vertical shaft. The point of ignition can also be hand-controlled by turning a sleeve beneath the timer.

The Atwater Kent system works on the open circuit principle and there is no danger of running down the batteries by leaving a switch closed.

Fig. 221 illustrates the Delco system. This system includes starting, generating, ignition, and lighting systems, all combined in one. A motor-generator set performs the function of cranking the engine and of supplying electrical current for ignition, lighting, sounding the horn, and charging the storage battery. The motor-generator consists of a dynamo with two field windings, and two windings on the armature with the commutators and corresponding sets of brushes. This construction is made in order that the machine may work both as a starting motor and as a generator. The ignition apparatus is incorporated in the forward end of the motor-generator. A combination switch is used for the purpose of controlling the lights, the ignition, and the circuit between the electrical generator and the storage battery.

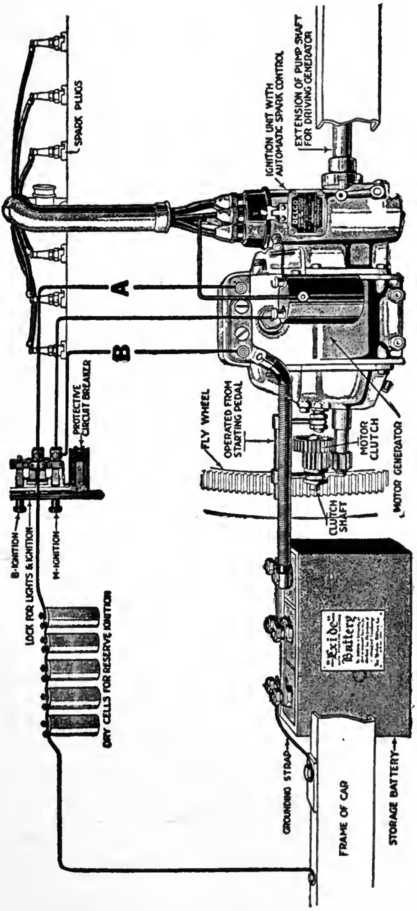


FIG. 221.—Delco ignition, starting, and lighting systems.

For ignition the Delco system employs a non-vibrator type of induction coil with a timer in the primary circuit, and a distributor. A governor for automatic spark advance similar to that of the Atwater Kent, but of different design is employed. In Fig. 221, if button *B* is pulled out, the current for ignition will be supplied by the dry cells. By pulling button *M*, current will be supplied through wire *A*, if the generator is in operation, or by the storage battery through wire *B*.

Automobile Starting Systems.—Automobile motors are started by hand cranking or by some automatic starting device. Before the motor is cranked the carburetor throttle lever on the steering wheel should be moved to a position where the throttle is open. The spark should be shifted to the retard position, as failure to do this may result in the engine kicking back on account of back firing. The gears should be placed into neutral position.

In cranking by hand, the crank should be pushed in as far as possible and turned in the clockwise direction until it catches. The motor should start if the crank is given a quarter or a half turn in the right direction. In cranking an engine, always set the crank so as to pull up. One should not bear down on the crank.

Electric starting devices are usually employed in modern automobiles. An electric self-starter consists of an electric generator for furnishing electricity, a storage battery, and an electric motor to crank the engine. The electric starting system is also supplied with switches for the purpose of controlling the supply of current; with protective devices such as fuses or circuit-breakers to prevent the discharging of the storage battery or damage to the coils, motor, or lamps; with an electric regulator to maintain constant voltage for the various speeds of the engine; and with electric meters for the purpose of showing the amount of current supplied by the generator to the storage battery and for indicating how much current is being supplied by the battery for ignition and lighting.

Electric starters are built in the single-unit, the two-unit, or the three-unit system. In the single-unit system the generator and motor are in one unit and this motor-generator is used for cranking the engine, for charging the storage battery, and for furnishing current to be used for operating the engine ignition system and for the automobile lights. In the two-unit system a separate motor, which receives its current supply from the storage battery, is used for cranking the engine. The electric generator supplies current for charging the storage battery and also for ignition and lighting. In the three-unit system a magneto furnishes current for the engine ignition system; a separate direct-current motor, supplied with current from a storage battery, is used for cranking; while the electric generator is used only for charging the storage battery and for operating the lights.

Mechanical starters are also used to a limited extent on small cars, but have been largely superseded by electric starters. Some mechanical starters utilize springs, which when released revolve the engine crankshaft. Other mechanical starters depend for their action upon a clamp, but are mainly hand-cranking devices with the driver remaining in the seat. Safety cranks are also manufactured for the purpose of reducing the danger of an accident in starting.

Automobile Lighting.—Electric lights are used almost exclusively on modern automobiles. The electricity for illumination is usually secured from a storage battery. In the cars with electric starters, the storage battery is recharged from the generator; in other cases the battery is recharged from an outside source. In some automobiles, notably the Ford, alternating-current magnetos furnish lighting current while the car is in motion.

A car lighted with a battery charged from an outside source is equipped with a storage battery of 80 to 100 ampere-hour capacity which supplies current for illumination and for blowing the horn. This lighting storage battery is usually not used for engine ignition, unless the car is equipped with a dynamo to recharge the battery. When the storage battery is used for lighting, ignition, and starting, its capacity should be at least 90 ampere-hours.

Management of Automobiles.—Before an attempt is made to start an automobile the operator should be certain that the fuel tank has sufficient gasoline, that the gasoline valve from the tank to the carburetor is open, that the lubricating system is in good working order, that the radiator is filled with clean water, and that the engine ignition system is working properly. The transmission system should be thrown into neutral position, the spark lever should be shifted to the retarded position, and the carburetor throttle should be partly opened before the engine is cranked. The rules given in the discussion of starting systems should be followed in starting an automobile by hand cranking. With electric self-starters, the starting pedal is pushed forward or down as far as it will go and held until the engine starts. As soon as the engine starts the foot should be removed from the starter pedal.

Easy starting may be obtained by throttling the air just as the engine stops, thus leaving a rich mixture in the cylinders. In extremely cold weather, or after prolonged standing of the car, it may be necessary to prime the carburetor or even to inject gasoline into the cylinder through each of the priming cups.

When the engine starts, the spark lever should be advanced. To start the car, the emergency brake is released, the clutch is disengaged, while the transmission gears are thrown into low gear forward, and the foot accelerator and the spark lever are operated to take care of the increased load on the car. In changing from low to intermediate and to high speed, the clutch is thrown out, the gears are shifted, the clutch is thrown in mesh, and the throttle, or foot accelerator, is adjusted for proper operation.

To stop an automobile, the motor is slowed down by removing the foot from the accelerator, the clutch is disengaged, the service brake is operated so that the car comes to a gradual stop, and the transmission gears are shifted into neutral position.

To stop quickly the operator presses on both pedals, releasing the clutch and applying the service brake, while applying also the hand emergency brake.

To reverse, the car is stopped, the reverse gear is shifted, and the clutch is thrown in slowly.

Details concerning the care of a car are given in manufacturers' instruction books and will not be repeated here.

An automobile engine will smoke if too much lubricating oil is used, if the lubricating oil is of poor quality, if the piston rings are worn or broken, or if the mixture of air and fuel is incorrect.

Engine hissing may be produced by loose or broken spark plugs, by leaving priming or relief cocks open, by having exhaust pipe loosely connected, or by leaky gaskets or intake manifolds.

Irregular action of the automobile engine may be due to incorrect fuel mixture, poor wiring such as defective insulation or defective connections, carbon deposits, poor fuel, or defects in carburetor, magnetos, spark plugs, or mechanism.

Misfiring is often due to carbon deposits on the spark plug. Overheating of the engine may be due to incorrect valve or spark timing, defective water circulation, clogged radiator, or a lack of proper lubrication Engine knocks are due to rich mixture, too much spark advance, carbon deposits in the cylinder, loose or worn bearings, loose flywheel, or lack of lubrication.

TRUCKS

Most of the essential parts of a truck are similar to those of an automobile, but are usually heavier to stand the greater strains imposed by the conditions under which a truck operates.

Power Plants for Trucks.—The truck power plant is usually a four-cylinder vertical poppet valve type of internal-combustion engine, which operates on the Otto four-stroke cycle. Six-cylinder engines are employed to a limited extent in trucks.

A standard type of float-feed carburetor is used, such as the Stromberg plain tube or the Zenith. Some trucks are equipped with special carburetors, such as the White, the Packard, or the Pierce Arrow.

Truck motors are cooled with the forced water circulation system and are usually provided with tubular radiators, in which the upper and lower tanks are connected by a series of tubes through which the water passes. Some of the lighter trucks are equipped with cellular radiators similar to those used on automobiles.

The jump spark system of ignition is employed. In some makes of trucks, batteries are used for furnishing current when starting and magnetos supply electricity for ignition after the motor has attained normal speed. This is called the dual system. Most trucks are equipped with a high-tension magneto. In some cases trucks are provided with two independent ignition systems, including a high-tension magneto and a distributor.

Power Transmission Systems for Trucks.—The power transmission systems of trucks and of automobiles include the same elements.

Some trucks employ a dry multiple disc clutch and others use a wet multiple disc clutch. Dry or wet single-plate clutches are also used for trucks. The principle of operation of the plate clutch is similar to that of the cone clutch. The friction plate is independent of the flywheel and of the housing and a spring holds the friction surfaces in contact. The friction surfaces are separated by depressing a foot pedal.

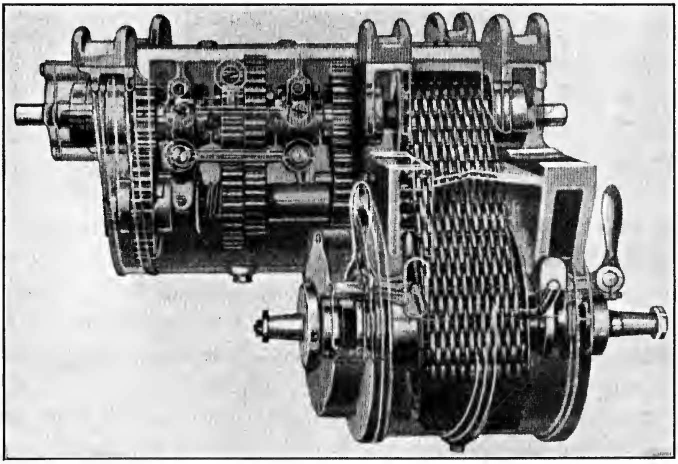


Fig. 222.—Truck transmission.

The transmission of a truck is usually of the selective type and includes three speeds forward and one reverse. Some trucks employ a four-speed transmission system. Such trucks have direct drive on the fourth speed and three lower gear ratios. To reduce the danger of stripping gear teeth the gears of the counter shaft and main shaft of the transmissions for heavy trucks are placed permanently in mesh, the drive being obtained by the use of shifting forks or clutches. A typical transmission for a heavy truck is shown in Fig. 222.

The propeller shaft carries the power from the transmission through the universal joints to the rear axles. The power from the propeller shaft to the rear axle is transmitted either by shaft or by chain drive.

The shaft drive is the most common for trucks as well as for automobiles. The shaft drive transmits the power to the differential, which is placed on the rear axle through bevel, helical, or worm gears. The bevel gear drive is seldom employed for trucks. The helical or spiral bevel gear drive is more satisfactory, as two or more teeth are in mesh at one time, reducing irregularity in wear. The worm gear drive is particularly well suited for trucks, on account of the large gear reduction which this drive makes possible. A large differential gear reduction decreases the torque required to drive the rear wheels.

For heavy trucks chains are often used for the final drive in order to obtain the greatest possible speed reduction. In such trucks the differential is not placed on the rear axle, but is contained in the same housing with the transmission. From the differential the power is transmitted to jack shafts, which drive the rear wheels by means of chains.

Some trucks are constructed so that they drive and steer with four wheels. In such cases the power from the transmission is transmitted to two differentials. One differential serves to transmit the power to the front wheels and the other to the rear wheels.

The differential of the truck has the same function as that of the automobile and permits the drive-wheels to revolve at different speeds without interfering with the operation of the truck.

TRACTORS

Essential Parts of a Tractor.—A tractor consists of the following essential parts:

1. *Power Plant.*—This in the case of a steam tractor includes a steam engine, a boiler, a pump or injector, steam and feed water piping, fuel hopper, water storage, and the ordinary steam power plant accessories. Gas tractors employ an internal combustion motor burning gasoline, kerosene, or some heavier oil.

2. *Speed Reduction Gears.*—A train of gears must be interposed between the motor and the drive wheels in order that the tractor may be propelled at a very low speed.

3. *Reversing Mechanism.*—A steam tractor is reversed by a Stephenson link motion similar to that used for reversing loco-

motives or by some form of single eccentric radial valve gear. Gas tractors employ a train of gears.

4. *Steering Mechanism.*—Steering is usually accomplished by turning the front axle.

5. *Friction Clutch.*—A friction clutch is necessary for the purpose of disengaging the motor from the propelling gear. The expanding cone and the expanding shoe clutches are used in addition to those explained. Fig. 223 illustrates an expanding shoe clutch.

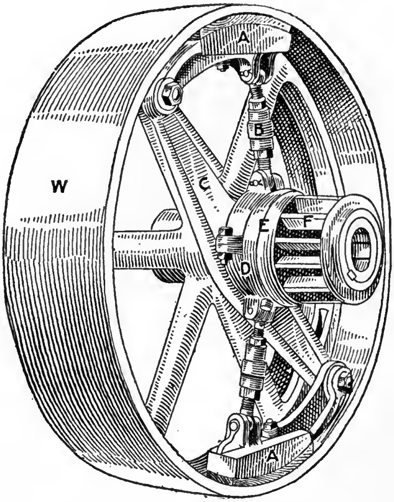


Fig. 223.—Tractor clutch.

6. *Differential.*—The differential (Fig. 224) is similar to that used on trucks and its function is to allow one drive wheel to revolve independently of the other.

7. *Tractor Frame.*—The frame supports the various parts and keeps them in proper alignment.

8. *Drive Wheels and Steering Wheels.*—Usually the two rear wheels are the drive wheels and the two front wheels are used for steering. Some tractors employ a drum for driving, several makes are constructed so that the front wheels are the driving wheels, and in other makes all four wheels drive. Tractors are also built on the "Caterpillar" principle and employ a crawler instead of a wheel or drum.

Steam Tractors.—The steam tractor, or traction engine, is usually equipped with an internally fired boiler. Some builders use the return flue type, others the direct flue or locomotive type.

Coal, lignite, wood, straw, or crude oil are used as fuels for steam tractors.

The feed water is delivered to the boiler by an injector, a direct-acting steam pump, a cross-head pump, or a gear-driven pump. Some tractors employ two independent methods for feeding water to the boiler.

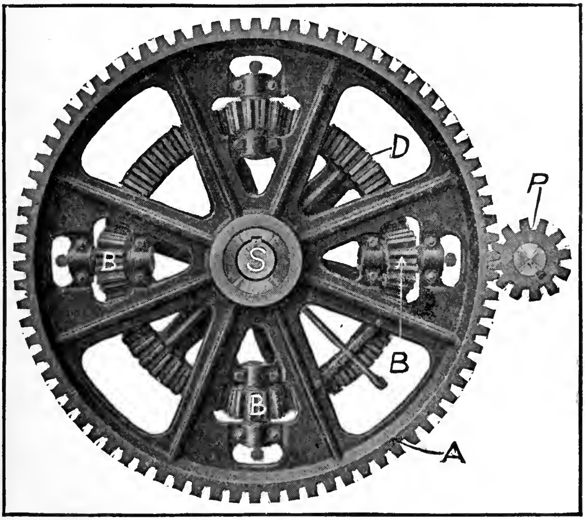


Fig. 224.—Tractor differential.

Feed-water heaters are used in connection with the better types of steam traction engines.

A simple type of slide valve engine is employed. Some tractors are provided with double-cylinder engines. Compound engines are also used to some extent.

Gas Tractors.—The use of the gas tractor has been increasing much more rapidly than that of the steam tractor. Gas tractors are made in many different sizes, prices, and special designs suitable for various uses. A gas tractor can be started much more quickly than one propelled by a steam engine and requires less attention.

The motors of gas traction engines usually operate on the Otto four-stroke cycle and use gasoline or kerosene for fuel. The motors are either vertical or horizontal and operate at moderate speeds as compared with the motors used on automobiles. The vertical motor resembles the truck motor, but is usually heavier. Fig. 225 illustrates the type of motor commonly used on gas tractors.

Float-feed carburetors of the single jet automobile type are generally used.

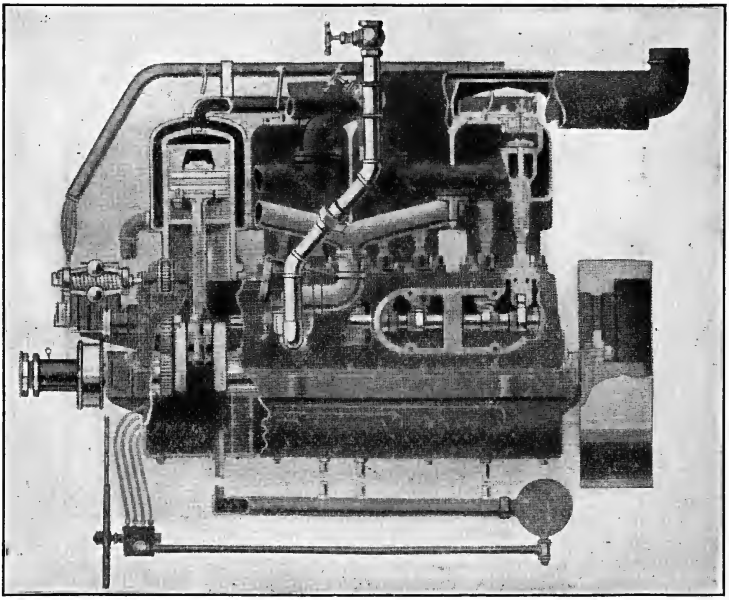


Fig. 225.—Four-cylinder tractor motor.

Nearly all tractors employ the jump-spark ignition system. The ignition system differs from that of automobiles in that magnetos are commonly employed.

Rating of Tractors.—Two ratings are usually given to tractors. One is in brake or belt horsepower. This indicates the power developed at the shaft of the engine, which can be used for driving various machines by means of belt drive. The other rating is the tractive or draw-bar horsepower. The tractive horsepower is usually one-half to two-thirds of the brake horsepower, depending upon the transmission gearing and on the character of the ground over which the tractor must be propelled.

Care of Trucks and Tractors.—The general directions given concerning the care of an automobile apply to the truck and tractor. Wearing surfaces must be kept well lubricated and lost motion in bearings must be avoided.

The steering mechanism of the tractor is less sensitive than that of the automobile or even of the truck on account of its slower speed and the lower gear ratio of the steering wheel.

Overloading a truck or a tractor is a serious mistake. The life and usefulness of any piece of machinery is increased by proper housing and systematic upkeep. The lubricating system of the motor should be examined daily. Frequent inspection should be made to determine the condition of the spark plugs, the alignment of the wheels, condition of the brakes, clutch, springs, rods, cylinders, and bearings. Valves should seat properly and should be correctly timed.

Problems

1. Make clear sketches showing the mechanism of an automobile steering gear.

2. Make a clear sketch of a universal joint.

3. Prepare a table showing the important differences in the specifications of automobiles and of trucks.

INDEX

Potter + Calderwood
Elements of steam
+ Gas power engineering

~~4 copies~~