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COLUMBIA UNIVERSITY LECTURES

POWER

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PREFACE

It is the object of the series of lectures included in this volume to point out the enormous effect that the substitution of mechanical power for hand and animal labor has had on the organization of society and the conditions of living, and by presenting the development of power machinery to show what sort of ideas have produced this result. The effect of power machinery is soon told and readily understood; but it is not so easy, though far more important, to show how the men who are responsible for what has been done have thought and worked, and with what kind of things and with what reasoning those men must deal who are to take up the responsibility for future progress. The bulk of the subject-matter, accordingly, is concerned with the apparatus and machinery for the converting of natural energy in any of its available forms into useful work, together with the physical processes for the execution of which that apparatus was devised.

C. E. L.

CONTENTS

POWER

I

THE RELATION OF MECHANICAL POWER AND MACHINERY TO SOCIAL CONDITIONS

Recorded or unrecorded history, the story of things that have happened, with explanations of the probable reason, may be regarded as a most useful, if not a necessary, guide to the conduct of present-day affairs; whether it be concerned with wars and governments or the customs and mode of living of the people; whether written in books carrying the title of history or told by the old to the young, treating of ancient times or the events of yesterday. For a long time writers of history were content with records of armies and battles, and their relation to the fall of one empire and the rise of another. Little, if any, attention was given to such ordinary questions as the sort of food the people ate, the kind of clothes they wore, of what sicknesses they died, at what occupation they labored, and with what tools to assist them, what compensation they received, and how the product of their labor was obtained by the non-producer, — all of these questions of far more vital importance to the welfare of the average individual than the quarrels of nations. While some little information of this class may be found in general literature, not ordinarily classed as history, the topics there discussed seldom refer to the daily work of the mass of the people, by means of which the whole population was fed, clothed, and housed, or the relation of these questions now generally classified as industrial to the social or governmental organizations, the welfare of the individual, or changes of state. Modern historians, however, are waking up to the fact that present conditions have been brought about not so much by the victories of war as by the practice of every-day acts of peace, and that a diagram of a loom for weaving cloth may really be a more valuable thing to study than a map of the battle of Waterloo.

There seems to be little doubt now that industrial conditions are of primary importance in shaping the various conditions of human affairs, and are fundamental to the mere existence of government, but this did not appear so clearly in early times. In the days when the great body of the people were farmers, when little mining was practised and practically no manufacturing, about the only unusual or extraordinary happenings were the wars, so it is not surprising that a history of the period should be a record of these conflicts. Later on, however, things changed, industrial affairs assuming more importance as factories were built, drawing men from farms and concentrating them in factory towns, and stimulating the development of steamships and railroads to bring raw materials to the factories and to distribute their products, giving more and varied employment to others, and supplying all with new forms of the necessaries and luxuries of life, and completely changing the whole social organism.

The great change in conditions, which made those things which formerly seemed all-important assume minor significance, and accented the truly greater importance of industrial affairs, began a little over a century and a half ago, with the invention of spinning and weaving machinery and the steam-engine to drive it. Tracing from that time the progress of the substitution of mechanical power and machinery for hand labor, by which those things that people want can be produced better and cheaper than ever before, as well as new things previously not thought of, but which are wanted as soon as seen, will serve to explain modern conditions as no other study can. Instructive as such a review of industrial history may be, it is as nothing compared to the value of an understanding of the industrial conditions of the present time. It is far better to know how a hat is made, a trolley car works, or the fruit of California can be sold cheaply in New York, three thousand miles away, than any of the facts of history, though the latter may precede and make easier the comprehension of the more complex present. Referring to the importance of these industrial changes, which is slowly but surely becoming accepted as it should be, is a well-worded statement in Robinson and Beard's "Modern Europe."

"The story of mechanical invention is in no way inferior in fascination and importance to the more familiar history of kings, parliaments, wars, and constitutions. The chief factors in it never stirred an assembly by their fiery denunciation of abuses, or led an army to victory, or conducted a clever diplomatic negotiation. On the contrary, their attention was concentrated upon the homely operations of every-day life; the housewife drawing out her thread with distaff or spinning-wheel, the slow work of the weaver at his primitive loom, the miner struggling against the water which threatened to flood his mine. They busied themselves perseveringly with wheels, cylinders, bands, and rollers, patiently combining and recombining them until, after many discouragements, they made discoveries destined to alter the habits, ideas, and prospects of the mass of the people far more profoundly than all the edicts of the National Assembly, or all the conquests of Napoleon taken together."

The often-heard characterization of our times as the "industrial age" and of our most influential citizens as "captains of industry" are indications of growing respect for the manufacturing and transportation industries not merely as occupations or means of employment, but as world-shaping forces stronger than armies and navies, and marks of appreciation of the fact that the training of engineers is more important than that of generals. It is not so generally realized, however, that all this would be quite impossible without power-generating machinery, which, receiving the water of the river or the heat of fuel as sources of energy, changes them under man's control, and finally turns the wheels of industry. It is difficult to believe that any one with ordinary natural curiosity, after having his attention drawn to these facts, and knowing that practically every article that he uses, especially in cities, is power produced, at least in part, can fail to inquire how it was brought about; in just what way man has succeeded in harnessing nature to do his will; for the employment of power-generating machinery is a demonstration of his control over those forces of nature that once struck fear into the hearts of men by lightning, fire, and flood.

When, in addition, it may be promised that an examination of the power-generating processes and machinery, on which so much of general interest and personal welfare depend, will also reveal the working of broad, philosophic law applicable to all human affairs with profit, the systematic location and reduction of waste in all things, then mere curious questioning may well be expected to yield to enthusiastic study.

We are every moment surrounded by manufactures and results of mechanical power and driven machinery in almost infinite variety. Not only are the clothes, hats, and shoes we wear produced by power-driven machinery, at least in part, but so also are all the fabrics of the household, — linens, carpets, and hangings, the furniture, glass, chinaware, and metal house furnishings, and practically all that enters into the making of the house itself, — cement, brick, pipe, nails, furnaces, radiators, and lamps.

In addition, we use power-generated electric light and bathe in power-pumped water, ride in powered cars and boats, make war with power-made guns and ships consisting of several million dollars' worth of machinery each. The very food on our tables is drawn from the waters, forests, and farms of the earth by highly developed systems of transportation, preserved by machine processes or stored between production and need in power-cooled refrigerators, and we cool our beverages by manufactured pure ice.

In order that we may just exist, we require a supply of food and clothing, while comfortable living adds the necessity of housing with heat, light, and water, finer clothing and more choice food. To supply the necessities, comforts, and luxuries of present-day life requires a most complex series of operations by men with knowledge of nature's stores, and of the means by which they can be brought from the hidden places at the extremes of distance, and changed when necessary to that form which may be desired. Seldom are nature's stores of substances found in suitable form for use; but man early learned to change their form by hand, and devised tools to assist in the cutting of stones, the weaving of grasses and fibrous wool of animals into cloth; and later to use natural energy to assist, by baking clay to form bricks and pots, and by heating certain rocks to get copper and iron, though for a long time there was no realization of the fact that the use of fire to assist change of form was a demonstration that heat was one kind of natural energy, or that it could be made to do common work of lifting, pushing, and pulling.

A still earlier though similarly unconscious use of heat energy was made when man planted seeds in the earth to obtain a supply of food. These seeds grew, and in the growing the substances of the earth in which the seed was placed, together with the air and water which surrounded it, were transformed into the potato and the tree by the chemical and molecular forces derived from the energy of the sunshine, binding up the sun's energy in the new plant form taken by the primary inanimate substances. This change of substance form, through the assistance of natural energy, by which the useless may be made useful, and of which life itself is the best example, taught a lesson unlearned through countless ages, during which but little progress toward what we are pleased to term "civilization" was made. No one dreamed that energy was being used, or even that there was such a thing, in those days, and it is not too much to say that the conception of energy which recognizes heat, work, electricity, magnetism, sound, and light as interchangeable energy manifestations was one of the most significant in point of results that the world has ever seen.

The discovery that energy was available in nature for the doing of man's work is sometimes traced to his natural indolence when he placed sails on boats, and paddle-wheels under waterfalls to lift weights, even though no idea existed that the capacity of the moving water and moving air to do these things was proof of the existence of energy in nature, and exactly similar to the capacity of fire to melt things or extract metals from ores.

From the practice of these simple processes of form changing, such as weaving and the application of wind and water energy to the service of men, there is a long period during which no real progress worth mentioning was made, and which came to an end only with the general realization, first, of the possibility of devising combinations of sticks and metal parts to reproduce the movements of hands and fingers and eliminate the guidance of the eye; in short, to make things wanted from other things available; and secondly, that the heat of burning fuel, if properly applied to other substances and metal parts, was capable of doing the same sort of work as the waterfall and the wind.

The general process of changing useless materials into useful and serviceable things is termed to-day "manufacturing," when carried out systematically and repeatedly in the same way, while the processes by which natural energy of whatever form can be made to do man's work are called rather incorrectly "power generation." Together these processes of manufacturing and the generation of power, carried out in the machinery of manufactures, perform the function of changing natural things into other things that people want; so man has learned in part nature's own lesson of organic life and applied it to his needs and pleasures.

Culture and the full enjoyment of life are possible only when the demands for the necessities have been satisfied; or, speaking more broadly, national prosperity is a necessary prerequisite to civilization, and that nation is most permanently prosperous in which production of wealth is the more universal occupation; wealth derived primarily from the farm, the sea, the mine, and the forest, the raw materials of which are augmented in value by manufacture, giving rise to transportation and commerce. In all of these industries, basal to national security and happy living, mechanical power plays a part, more important in some than in others, but an important part in all. Practically all our fish products are gathered in power boats to-day; mines that can raise the ore to the surface without power are rare, and still more rare are the ores that can be reduced to metal without it; the farmer is resorting more and more to power, one manufacturer alone last year having sold 30,000 gasolene engines for farm use. It is, however, the other two industries that are most dependent on power; manufacturing owes its very existence to our ability to generate, apply, and control power economically, while power is the prime element in transportation over land and water. These two great businesses of making things and moving them, now classified as the industries of manufacturing and transportation, underlying practically all of commerce, owe their present state to power, and their future is largely a power problem.

Clearly as does a review of these things indicate our dependence on the use of power applied in the industries, it will be helpful in reaching a measure of the magnitude of the interests involved to examine some statistics drawn from the last United States Census Reports for the year 1905. From these reports it appears that the manufacturing and steam-railroad industries alone represent a capital valuation of nearly twenty-four billion dollars, about equally divided. The railroads of the country alone represent a mileage of 213,932 miles, or enough to go eight and a half times around the earth, while the manufacturing industries reported over two hundred thousand establishments. These together gave employment to nearly eight million people, about six million in manufacturing and over one and a half million on the railroads, paying them on the average $640 each on the railroads, and $550 in the manufacturing classes, the manufacturers' pay-rolls aggregating over three billion dollars ($3,186,-

301,763) yearly. Raw materials from mine, farm, forest, and sea used by the manufacturers cost them over eight and a half billion dollars ($8,503,949,756), and the processes through which they were transformed increased their value about 70 per cent, adding to the wealth of the country over six billion dollars, the manufactured goods becoming worth nearly fifteen billion dollars ($14,802,147,087). These industries now employ power to an extent approaching 50,000,000 h. p., and the whole is not reported, but for each horse-power that is reported the products were worth $1152, and $248 in wages were paid in the manufacturing industry. The present total is estimated from the following figures, Table I, which do not include automobiles, hoisting, pumping, and compressing engines, and independent engines used in buildings not engaged in manufacturing, such as hotels, which should be added, and which would considerably increase the reported total, while the total to-day must be much increased over the census year of 1905, as the rate at which the use of power has been increasing has been itself on the increase since the Civil War.

TABLE I

POWER IN USE BY LAST CENSUS. CORRECTED BY H. ST. CLARE PUTNAM

Manufactures (1905)	12,765,594
Mines and quarries (1902)	2,753,555
Street railways (1902)	1,359,289
Electric light and power stations (1902)	1,845,048
Telephone, telegraph, and fire alarm	3,148
Custom flour, grist, and sawmills, and industries omitted from Census	883,685
Naval vessels (1905)	777,598
Licensed merchant vessels (1905)	2,608,270
Locomotives (1904) equivalent	3,750,000
Total horse-power accounted for	26,746,187

In reporting the manufacturing industries, many establishments were omitted in accordance with the Bureau's definition of a factory as "an establishment in which there is an association of separate occupations to facilitate the combination of the processes into which the manufacture is divided, and producing goods for the general market stock rather than on the order of an individual." This definition excludes the small shoemaker, milliner, all the building trades, and similar kinds of business.

The greatest manufacturing industries may be judged by either the number of wage-earners or the value of products, and on this basis the following two tables are offered, from which it appears that each of five groups of industries employed over two hundred thousand wage-earners, and each of six industries produced goods valued at half a billion dollars or more.

TABLE II

Great Industries by Wage-earners

INDUSTRIES EMPLOYING OVER 200,000 WAGE-EARNERS

Industry	Number of Wage-earners
Lumber and timber products	404,626
Foundry and machine shops	402,919
Cotton goods	315,874
Steam railroad shops	236,900
Iron and steel works and rolling-mills	207,562

TABLE III

Great Industries by Value of Product

INDUSTRIES WITH PRODUCTS WORTH A HALF BILLION DOLLARS YEARLY

Industry	Value of Products Yearly
Slaughtering and meat packing	$801,757,137
Foundry and machine shops	799,862,588
Flour and grist mill products	713,033,395
Iron and steel works, rolling-mills	673,965,026
Lumber and timber products	580,022,690
Cotton goods	450,467,704

To supply the manufacturing industries with raw materials there are supported the other industries of lumbering, mining, farming, and fishing, each of which contributed, as shown in Table IV; over 94 per cent coming from farms and mines.

TABLE IV

Source of Raw Materials and their Distribution

Source	Yearly Value	Per Cent
Farm	$2,492,836,646	81.2
Forest	163,464,677	5.0
Mine	471,118,181	13.4
Sea	13.715,086	.4
	$3,141,134,590	100.0

Farm Products	Per Cent	Sea Products	Per Cent
Food products industry	63.6	Food products . . .	83.1
Textile industry . .	18.6	Chemicals	1.9
Leather goods industry	6.4	Miscellaneous . . .	15.0
Liquors and beverages	2.4		
Chemicals	3.9		
Tobacco	4.0		
Miscellaneous . . .	1.1		

Mine Products	Per Cent	Forest Products	Per Cent
Iron and steel goods . .	23.9	Lumber products . .	53.8
Chemicals	33.9	Paper and printing . .	15.6
Clay, glass, and stoneware	5.3	Chemicals	5.6
Other metal products .	29.8	Vehicles	1.6
Miscellaneous	7.1	Miscellaneous . . .	23.4

Not only does the manufacturing process add to the wealth of the country by increasing the value of the materials used nearly 80 per cent, but it also gives a value to the raw materials which they did not previously possess in their original state. There would be little demand for iron ore without the means of extracting the iron and making from it things that people want; fruit, vegetables, and fish are produced at definite seasons and are worth more since means of preservation and cold storage were developed than before; the machinery for making shoes has so increased the demand for shoes as to give increased value to hides, or an equal value to more of them. Coal tar was once an annoying by-product of gas-works, but is now a source of medicine, beautiful dyes, and perfumes; cotton seed has become valuable as the source of a useful oil; in 1860 it was refuse, in 1870 a fertilizer, in 1880 a cattle food, in 1890 a table food. Certain parts of animals slaughtered for meat were once annoying waste; now every part is utilized, and from the former waste by-products are made gelatine, glue, brushes, oils, buttons, medicine, and soap. What was once useless has been made useful, and that which had value has been given ever increasing value by manufacture, so that the prime producing industries of farming, fishing, mining, and lumbering may be said to be largely supported by the manufactures, transportation being the connecting and similarly dependent industry, and of this complex organism the vital organ is the power plant, without which the operating machinery would be lifeless and impotent.

In trying to realize the strides that have been made, which is the first step in the appreciation of our present situation, it will be helpful to look at some pictures, in addition to studying the figures which tell the story

FIG. 1

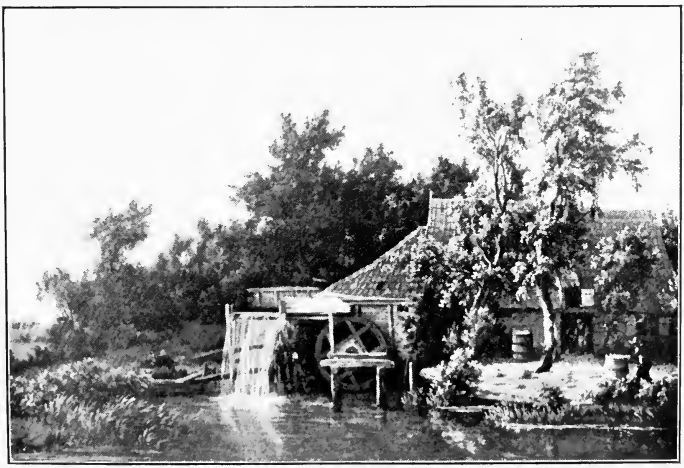

FIG. 2

of the magnitude of industries practically non-existent before power became available. In those days there was nothing but the water-mill and windmill, such as are shown in Figs. 1 and 2, and about all they did was to grind grain, lift hammers, or blow bellows for furnaces; boats were small and moved by sails, and

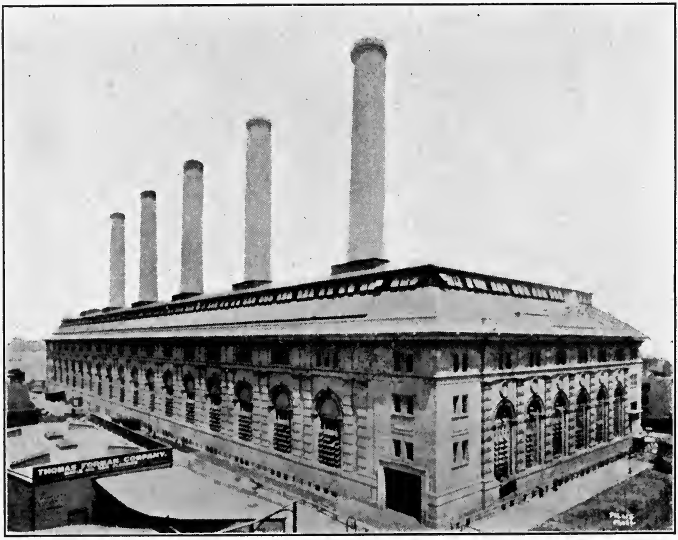

FIG. 3

land transportation was dependent on the horse. Compare these illustrations of the old conditions with the following illustrations of the present. The picture (Fig. 3) shows the exterior of the New York Subway power house, occupying a whole block, with a capacity approaching a hundred thousand horse-power, and filled with seemingly complicated machinery, as will be appreciated from the interior of one half shown in Fig. 4. This power station, while the largest, is only one of hundreds of similar ones located in every city in the country. A modern steamship, such as the *Kaiser Wilhelm* and others, would have been no

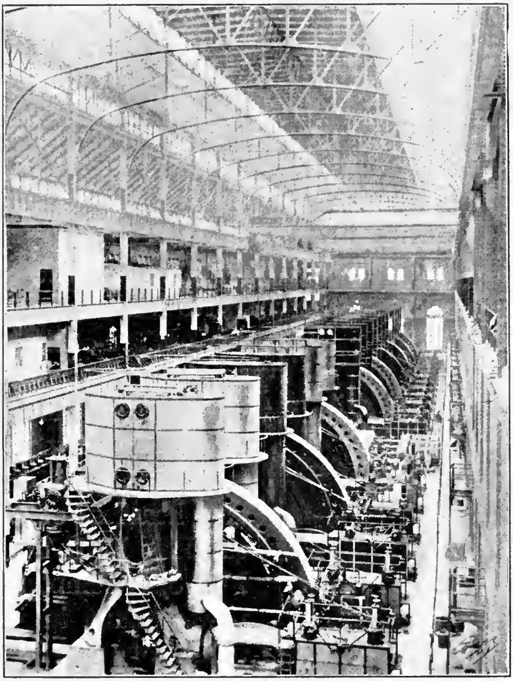

FIG. 4

more wonderful or unreal to the owner of the old windmill, or to the captain of the small sailing vessel of those days before the steam-engine, than would a vision of heaven. These vessels, some of them over seven hundred feet long, carry deep down below the water-line a large steam-power plant, such as is shown in the sectional view (Fig. 5), with nineteen boilers, each seventeen feet in diameter and shown in Fig. 6, supplying

Fig. 5

steam to ten engines of nearly fifty thousand horsepower, the size of which is clearly indicated in Fig. 7 by the man standing in the center of the picture.

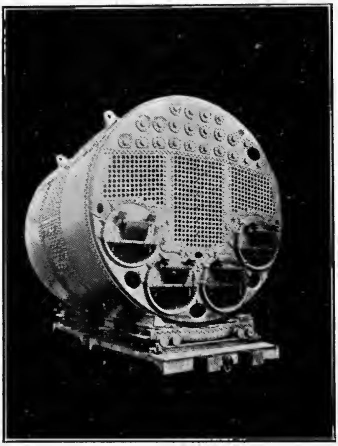

Fig. 6

No less impressive is the comparison of the old horse and wagon as the sole dependence for moving goods on land with a modern locomotive, one of the latest and heaviest of which for the Erie R. R. is shown in Fig. 8, a complete steam-power plant in itself, capable of drawing across the country half a hundred cars, each carrying fifty tons of coal, at high speed, and another for the New York Central, shown in Fig. 9, which is capable of drawing a heavy ten-car Pullman train over a mile a minute, making possible a journey to Chicago, of about nine hundred miles, in eighteen hours, maintaining an average speed, including stops for coal, water, switch, signals, and stations, of fifty miles an

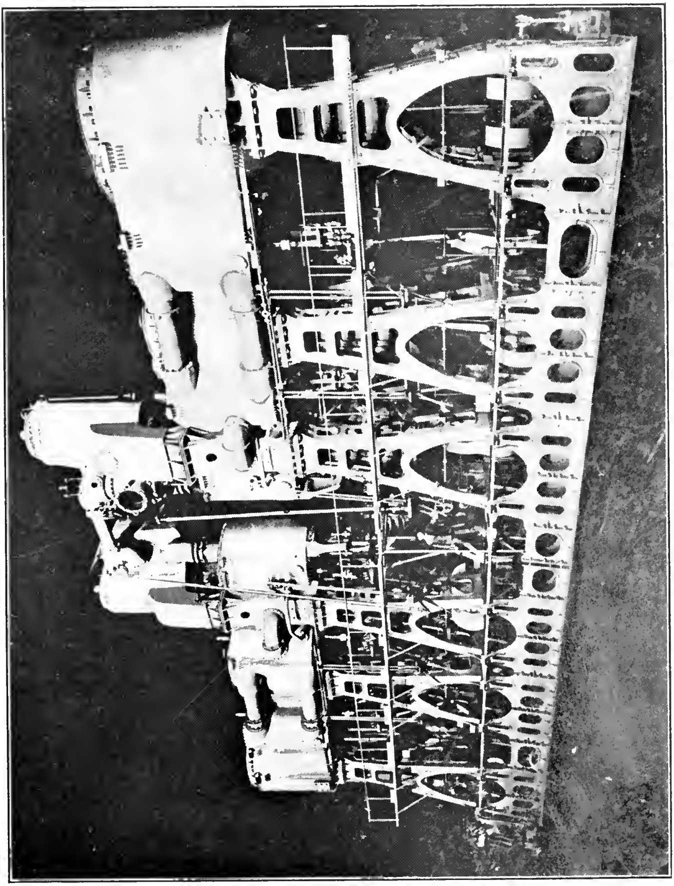

Fig. 7

hour. There are no statistics of steamship transportation available, but the railroad business, so largely supported by the manufacturing industries, is fairly well determined, and included in 1900 a passenger mileage of over one and a half billion miles, or over two hundred miles per capita of population, while the freight haulage was equivalent to one hundred and

Fig. 8

forty-one billion six hundred million ton miles (one ton hauled one mile).

Just as a comparison of the pictures of the modern power plants with the old wind and water mills is useful, so will be a brief survey of a few characteristic establishments of the larger manufacturing industries, which did not exist at all before the advent of the steam engine.

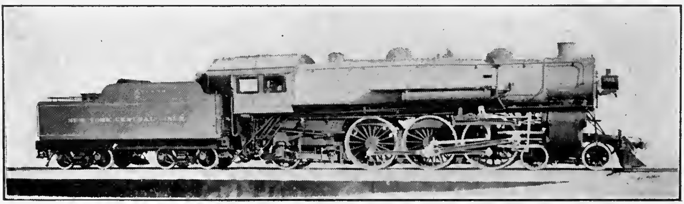

Fig. 9

Some of these establishments employ hundreds and even thousands of men, and constitute, with the homes of the workmen, the stores and homes of the tradesmen who supply them, fair-sized cities in themselves. The greatest manufacturing groups are of food-stuffs, iron and steel products, and textiles, and the following pictures of one establishment of each class will serve the purpose. The slaughter-houses, meat-product fac-

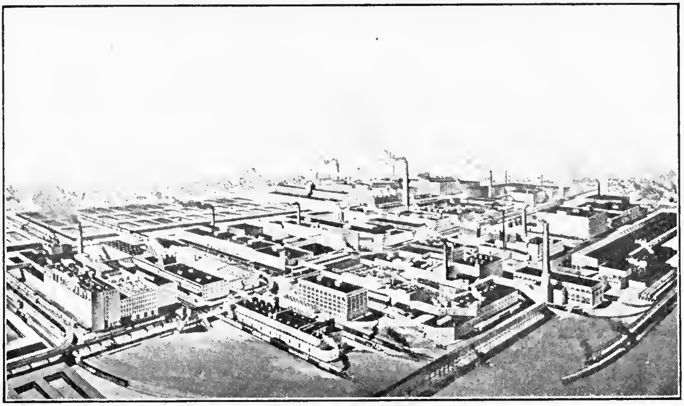

Fig. 10

tories, and cold-storage warehouses of Swift & Co., at Chicago, in which over ten thousand horse-power is used, are shown in Fig. 10; the Homestead Works

Fig. 11

of the Carnegie Steel Co. at Pittsburg in Fig. 11; the machine shop of the Allis-Chalmers Co. at Milwaukee in Fig. 12, and in Fig. 13 is shown the largest cotton mill in the world, located at New Bedford. This mill can house over five thousand looms for weaving cloth,

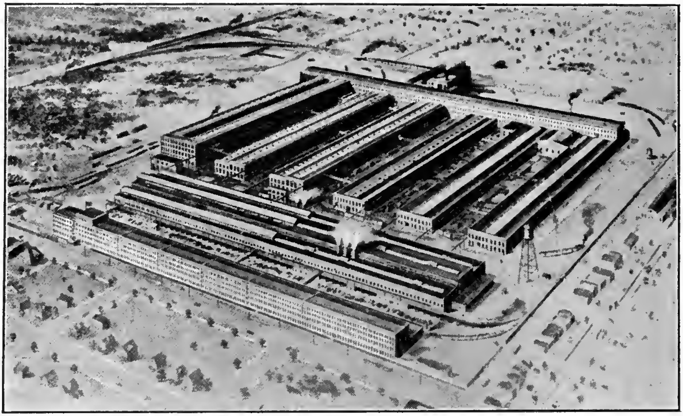

FIG. 12

and one hundred and fifty thousand spindles for making the necessary thread, all of which require some ten thousand horse-power to drive. The appearance of a

FIG. 13

spinning room showing the rows of spindles on the machines is shown in Fig. 14.

In round numbers, 85 per cent of all the power last reported in use in this country for manufacturing is derived from the combustion of fuel in steam-boilers, which deliver steam to engines and other apparatus capable of producing mechanical motion, and in the case of locomotives and steamships nothing but fuel-burning steam systems are in general use. About 14 per cent of the power generated on land for stationary use is derived from falling water, and about 1 per

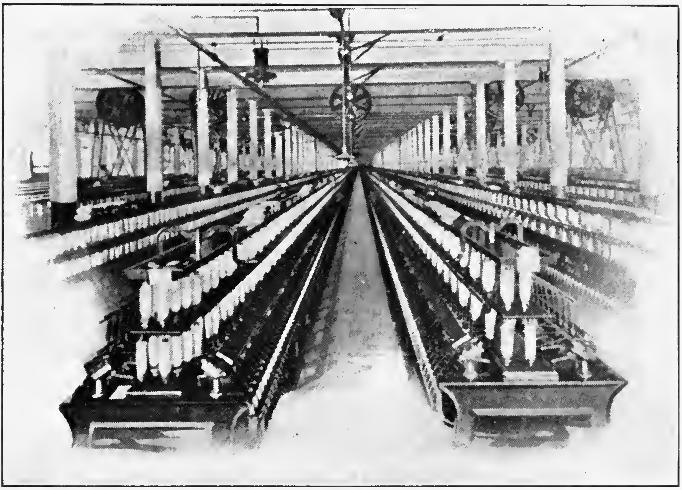

Fig. 14

cent from fuel turned into gas, mixed with air and exploded in gas engines, so that practically 86 per cent of the power in use on land, and all of that in use by railroads and steamships, are derived from fuel sources, and the remainder from natural streams. Fuel in some form is, then, our principal source of natural energy to-day, and is becoming increasingly our main dependence, as the percentage of power derived from streams has been continuously decreasing for forty years.

While the natural fuel may vary from hard, glossy, anthracite coal through various grades of soft coal to spongy peat in the solid fuel class, and through various oils in the liquid class to natural gas, all can be traced to sun-grown plants that have died and become packed together beneath earth and rock. The source of the energy of these fuels, then, seems to be traceable in turn to the heat of the sun, which produces the plant growth, and it is likewise the sun that evaporates water from the ocean, forming clouds, which are driven by sun-produced winds over the cold places, condensing the vapor into rain, which, falling on high places, produces rivers and waterfalls. Fuel, flowing river water, and the winds themselves all owe their energy to the sun, each manifesting its energy in its own peculiar way, and requiring a corresponding variety of machines to enable each form to do the same work at will. It has been estimated (Putnam) that the rate of increase in using power since 1870 has been such as to double the amount every ten years, shown in Fig. 15, and this same rate of increase applies as well to coal production, railroad gross earnings, freight ton mileage, passenger mileage, and value of agricultural products, proving absolutely the direct relation and dependence of the industries on power, and how serious will be the effect of lack of available power to meet the demands of industrial progress.

Coal is the main fuel dependence now, and there was produced in 1907 about 450,000,000 tons; in 1906 the railroads alone used 90,000,000 tons, for which was paid $170,000,000. At the present rate the known supply of anthracite will be exhausted in about 70 years, but the bituminous supply will last longer. It is estimated, by E. W. Parker, of the United States Geological Survey, that, if the present rate of increase continues for 150

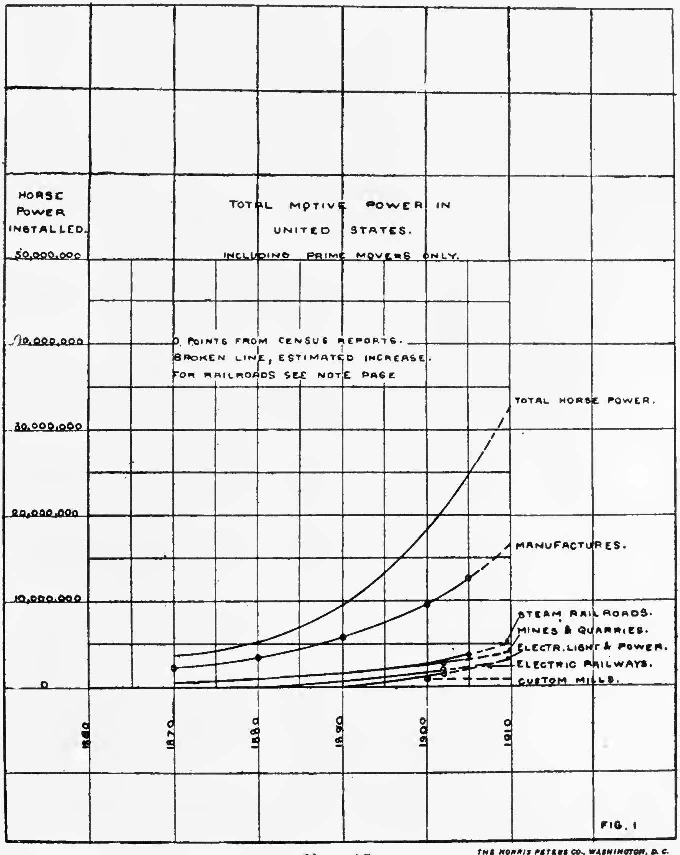

FIG. 15

years and the consumption then becomes constant, the supply will last 700 years. Similar estimates place the water-power capacity of our streams at 30,000,000

h. p., of which only 10 per cent is now used. So long as these natural supplies are depended upon, great care must be exercised in preventing waste; but it must be remembered that millions of square miles of land, especially in tropical countries, can be put under cultivation to produce wood for fuel, or the more rapid-growing substances like sugar-cane, sorghum, corn, or potatoes, bearing starch or sugar, which can be converted into alcohol in never ending supply. Just what fuel is to be used and by what system of machinery now or in the future, and whether fuel or water-power, will depend on the cost of the power by the system, which is a negative measure of waste. That source of energy and system of machinery that produces power with the least net waste is the one that will be used, — least waste of energy, of man's labor, of wear in machinery, and of investment, all together; and the prediction of the industrial future of the country, which in turn so powerfully influences its social and economic welfare, is resolved to a study of waste reduction.

By making studies of nature's substances and nature's stores of energy, and evolving means of using the latter to do the work of transporting the substances which are to be or have been changed to useful forms by similar power-driven machinery, not only has the wealth of the country been enormously increased and the general average of living likewise been raised, but direct employment has been created for ever increasing millions of population as wealth producers and traders in goods produced. The success of industrial undertakings, dependent as it is primarily on the economic use of power, is, however, and always will be, impossible without men, men of every walk of life, every degree of physical strength, mental power, and education. Equal as men may declare themselves to be before the law in their claim of a right to live without annoyance from others, no sane man can believe they are equal in attainments, or that the attainments of any one may not be increased by study, training, and experience. Were we all farmers or all weavers of cloth, there would be no possibility of finding an occupation for each, best suited to his ability, but the creation of these varied industries has had the effect of diversifying the duties of the army of men necessary to conduct their affairs. There is now work to be done in infinite variety and of different degrees of difficulty, so that the most ignorant man may find a useful place in the same establishment with the one most richly endowed with brain power developed to the maximum by education and experience, and capable of directing its affairs, which are often more complicated and difficult to administer correctly than those of state government.

To make a watch requires a very large number of processes on many separate pieces of metal; for each process tools and machine are devised and men trained to be skilful in their use; other men must buy the metal and the tools, sell the watches made, keep the factory in repair, keep records of cost, answer letters, secure money for pay-rolls, decide how many watches of each style shall be made, far in advance of the time they will really be wanted. Each man must work in definite relation to the others or the result will not be attained; so that the relation of the men to each other and to their tools and machines must be similar to the relation existing between the parts of the watch, even in spite of the fact that each man is human and is endowed with feelings and human perversity. The adjustment of these human relations to form the human machine, called the organization, is just as necessary in one kind of industry as in another; without such organization there would be no effective or economic manufacturing or transportation. The organization is the result of the attempts to reduce waste of human effort, such as results when one man has to repeat the work of another, or when one man opposes the efforts of another, or when any one is idle or fails to produce as much as he can. The systematic study of reduction of waste of labor, by management and organization systems, is a comparatively recent thing, undertaken only after years of effort in reducing waste of energy in power machinery, and waste of substances not in available form, but which could be made into new and useful forms by persistent trial. That men properly organized, trained, assisted, and properly paid can produce effects enormously greater than many times the same number of unorganized individuals, especially when assisted by capital, is a basal proposition of the industries, which we were as slow in learning as we were the lesson that nature's energy might be made to do man's work. It really seems as if the methods learned in applying nature's orderly laws controlling the generation of power and its application to machinery are to be the means of teaching us how best to get along with each other, to work in common to produce desired results with the least waste, as effectively and harmoniously as do the parts of the press that prints our daily papers.

II

MEANS EMPLOYED FOR THE SUBSTITUTION OF POWER FOR THE LABOR OF MEN

In the story of the development of power machinery, the part played by the rods, shafts, cylinders, and other elements of the mechanism as arranged and rearranged, important as it is, is subordinate to the ideas or conceptions of the physical processes that each rearrangement of well-known parts is devised to carry out.

It is more important to know just how steam when made should be treated to give the most work, than to make a steam-engine that will run; more important to know how combustible gas mixed with air should be treated to give an explosion with the highest possible pressure, than to make a chamber strong enough to hold the exploding mixture without breaking. Generalizing, it may be said that knowledge of what should be done is more important and of higher order than mere ability to make a mechanism that will work after a fashion.

Each process as it was conceived added a fact to man's understanding of physical nature, and in turn contributed to the discovery of the next. Air and water in motion, being capable of moving wheels with paddles, naturally lead a student to inquire how fluids, water, air, steam, etc., may be put in motion, a question which, once conceived, almost instantly answers itself, — by allowing them to escape from high-pressure chambers. The next logical step is to inquire how fluids may be prepared so as to have high pressures in chambers from which they may escape, and this leads to the discovery that water may be boiled in closed vessels by fire outside, or that explosions of powder and gaseous fuels may be caused to take place, or, more simply, that water may be led in pipes from the upper level of a waterfall to the lower level; and at once the three characteristic systems of power generation are understood, — water-power, steam-power, and gas-power systems. Experience with high-pressure fluid results in an understanding of its tendency to push apart the inclosing walls, one of which may be movable and on which the pressure may alternately act, as it moves back and forth, and there is in consequence developed the idea of another way of securing motion from fluids under pressure, besides the older one of jets striking paddle-wheels. An almost infinite number of combinations of mechanism parts and constructive details can be found to carry out each process, so that the processes are fundamental and the mechanisms incidental. It must not be understood, however, that these several parts may have infinite variety of form, or that they may be made of any convenient material, for there are limitations which must not be ignored. The mechanical elements must have such simple form as to be easily made by the shop tools and workmen; both the form and material of each part must be suitable for the purpose in strength, stiffness, flexibility, or wearing qualities; and the whole machine must be neither too costly to produce or to keep in repair, nor require too skilful an operator to manage.

The problem of power-machinery development is, therefore, divisible into several parts: First, what processes must be carried out to produce motion against resistance from the energy of winds, the water of the rivers, or from fuel. Second, what combinations of simply formed parts can be made to carry out the process or series of processes. These two steps when worked out will result in some kind of an engine, but it may not be a good engine, for it may use up too much natural energy for the work it does; some part may break or another wear too fast; some part may have a form that no workman can make, or use up too much material or time in the making; in short, while the engine may work, it may be too wasteful, or do its work at too great a cost of coal or water, attendance in operation, or investment, or all these together. There must, therefore, be added several other elements to the problem, as follows: Third, how many ways are there of making each part, and which is the cheapest, or what other form of part might be devised that would be cheaper to make, or what cheaper material is there that would be equally suitable. Fourth, how sensitive to care are all these parts when in operation, and how much attendance and repairs will be required to keep the machine in good operating condition. Fifth, how big must the important parts or the whole machine be to utilize all the energy available, or to produce the desired amount of power. Sixth, how much force must each part of the mechanism sustain, and how big must it be when made of suitable material so as not to break. Seventh, how much work can be produced by the process for each unit of energy supplied.

In the early days of power generation all these elements of the power problem were not recognized, but they were developed and studied about in the order named, a fairly satisfactory solution of the first part pointing out the existence of the next and the necessity of studying it, — the solution of a new question reacting on the older so that new solutions of it appeared that could not be conceived before. It may fairly be said that this systematic study has been receiving attention for about a century and a half, but divided into periods as the study advanced to the higher stages. For example, it was not until 1860 that the seventh element of the problem was successfully treated for those power systems depending on the heat given out by fuel as the source of energy. Although successful and commercially valuable steam-engines had been continuously produced for a hundred years, no one was able to calculate exactly how much of the heat in the steam might be converted into work by a mechanism ideally perfect, so that the goodness or badness of a mechanism could not be judged by any absolute scientific standard, but only comparatively. One engine might in operation produce a certain horse-power with less coal per hour than another, but no one could state positively why, which, of course, is the first step in rational improvement of economy; nor could the minimum possibilities of coal consumption for a system be calculated, so that the comparative value of competing systems could not be judged. This sort of calculation is now an every-day affair, which every engineer is capable of carrying out, and is the basis of all modern designing and improvement. The fact that it took over a hundred years after building useful engines began to arrive at a scientific conception of the fundamental processes which were being more or less imperfectly executed in machines designed largely by rule of thumb is doubly significant of the high order of mental development necessary for this conception, when it is realized that the first and second elements of the problem appear to have been understood to a degree sufficient to produce working models some two thousand years before, since operative machines were built at that time, even though they were not much more than toys.

The period of systematic and scientific power development is coincident with the true progress of the most basal of the several branches of natural philosophy, chemistry, physics, mechanics, thermodynamics, and the theory of elasticity of materials of construction; and there is no doubt that the steam-engine which was designed and built by workmen before these were formulated attracted the attention of philosophers who, in attempting to explain what took place in it, created a related body of principles by which future development was guided, and which are now the fundamental bases for the design of the future. Those men who became familiar with the natural sciences, and also with the shop methods of making machinery, and who brought both to bear on the problem of the production of machinery for specified conditions, combining the special knowledge of the scientist and shop mechanic, were the first mechanical engineers; and the profession of mechanical engineering, which is the term applied to this sort of business, was created out of the efforts to improve power systems, so as to make them more efficient and adapted to all classes of service, and to render that service for the least cost.

Nothing is more absorbingly interesting than the detailed history of power-system ideas, mechanism, and the economic production of both the machinery and the power itself, studied along with the parallel development of the natural sciences; but this is beyond the scope of these lectures, in which no more than the merest outline can be attempted, just sufficient to permit of a little understanding of modern machinery.

As has been already said, one of the earliest understood ideas applied to power generation is that water in motion may, by striking paddles on wheels, move them and itself lose some of its motion, or that the energy of motion can be communicated from one body to another. One of the earliest kinds of wheels based on this idea is shown in Fig. 16. The wheel was hung by its shaft, which was just a log of wood, over the surface of a fast-moving stream at such a height as would allow the paddles to dip into the water. This same fundamental idea, old as it is, is also one of the most modern, inasmuch as it is basal to the largest modern water and steam-turbines, for steam is a fluid that behaves much like water. It must not be understood that the basal idea consists in the dipping of paddles into a

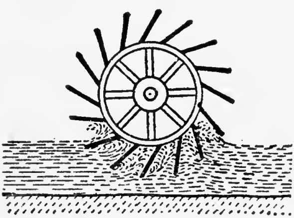

Fig. 16

brook; this is a mere incident, a convenient way of carrying out the real, fundamental principle, which is that moving fluids have energy by reason of their motion, which energy can be imparted to wheels by bringing the original fluid to rest in a suitable way. One of the largest water-wheels ever built, and which was designed to carry out as efficiently as possible this same idea, is shown in Fig. 17, as it appeared in the shop before shipment. The size can be appreciated by comparing it with the men standing beside it and on top of it. This wheel is at work below Shawinegan Falls in Canada, and develops 10,500 h. p., when supplied with water through an $11\frac{1}{2}$-foot pipe from above

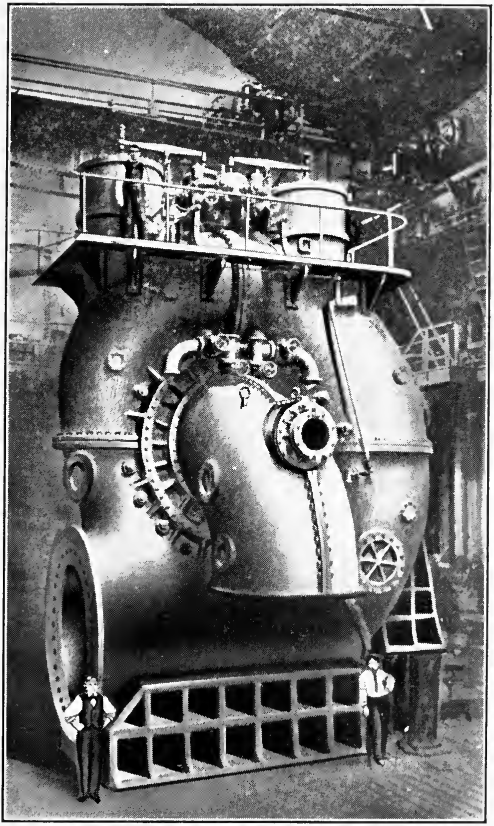

Fig. 17

the falls, the total effective drop being 140 feet. The vanes or curved partitions, equivalent to the paddles, are shown attached to the shaft in the picture of the runner, Fig. 18 Precisely the same basal principle or controlling idea is carried out, with suitable changes of structural detail, to adapt the mechanism to use steam instead of water in the steam turbine, shown in Fig. 19 as installed in the Potomac Electric Co. of Washington. Such machines as these are now built in sizes approaching 30,000 h. p. each.

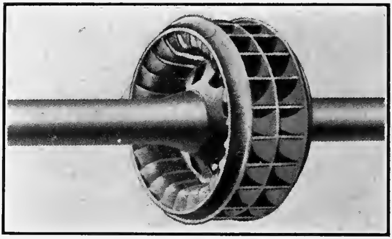

Fig. 18

In most of the modern turbines, which is the name applied to the most highly developed form of wheels designed to rob moving fluids, like steam and water jets, of their energy of motion, there are involved many other principles or ideas, some of which are very old and some of recent conception. One of these, easy to understand, is concerned with the way in which the steam or water may be conveniently set in motion. Water, led from an elevated tank or pond by pipes to a lower level, exerts a pressure tending to burst the pipe, which is more powerful the greater the drop in level, and the pressure tends to make water flowing from a hole or nozzle move faster the greater that pressure is. Similarly, water, steam, or air, or any other fluid, confined in a chamber under pressure, will escape from that chamber through a nozzle in a jet which will have a velocity determined by the pressure. The quantity of fluid that can escape, as well as the energy of the jet, will depend on the size of the hole and velocity of the jet together. It has always been found most

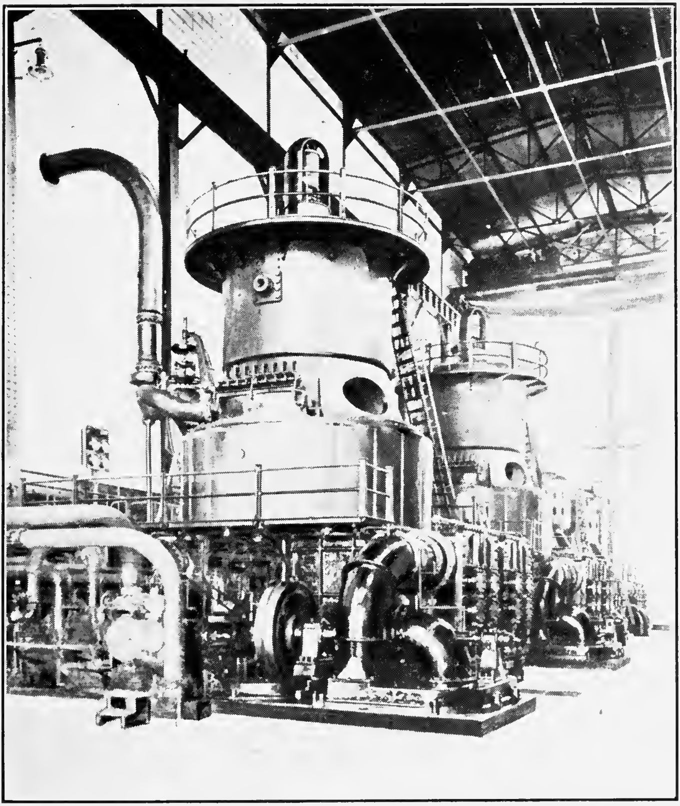

Fig. 19

convenient, because of the concentration of energy that results, to devise means of getting the fluid under pressure, and then allowing it to escape to give it motion, instead of depending on substances naturally in motion. These jets of fluid may be allowed to play on vanes or paddles in a great variety of ways, giving different types of motors all known by the class name of impulse wheels, several of which, intended for water, are shown in Fig. 20. Some of these have one nozzle and others

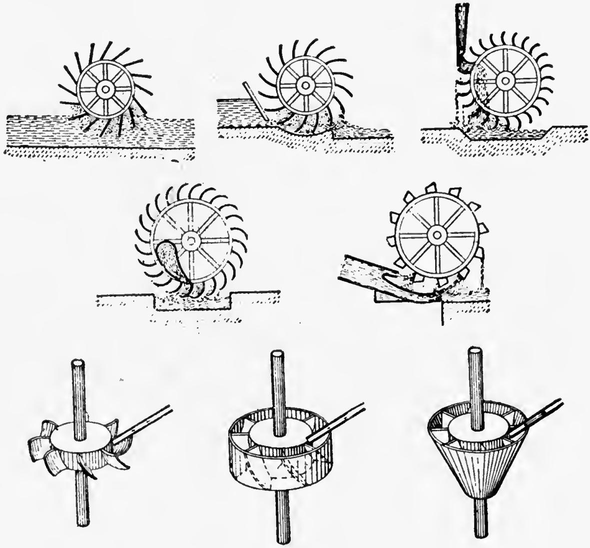

Fig. 20

many; the vanes have different forms and are variously disposed on the wheels. It required many years of study, experiment, calculation, and comparison to discover just what curvature and angle should be given to these vanes and nozzles to secure high efficiency, for while any such combination as shown will run, there is only one best form for each kind, and the determination of that best form is the principal problem of the designer to-day. To such perfection has this work been carried that it is now possible to predict, within one or two per cent, how much of the fluid energy a turbine yet unbuilt will be capable of transforming into useful work. A pure impulse wheel designed to receive jets of steam is shown in Fig. 21, together with four nozzles from which the steam is escaping, striking the curved vanes of the wheel, and in passing through having its direction of motion changed to give the impulse or push. A proper relation exists between the speed of the vanes, that of the steam jet, and the angles and curvature that will allow the steam to leave with no velocity at all, its original energy of motion having been imparted to the wheel; and these things can now be determined with precision.

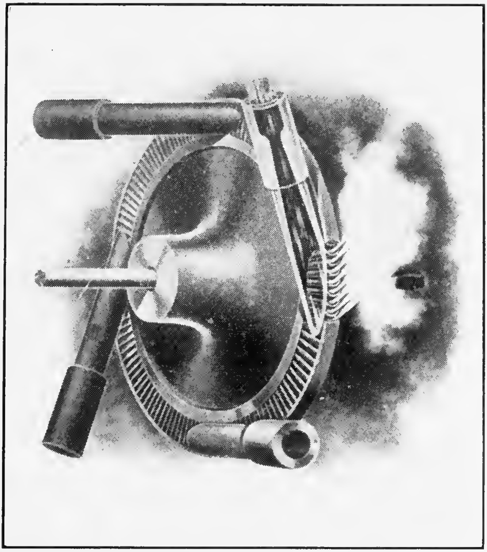

Fig. 21

When the water issues in a fast-moving jet from a nozzle, the nozzle is pushed backward, just as a gun recoils as its projectile moves out, and this principle of reaction is used in both water-wheels and steam-turbines, either alone or associated with the impulse action. Some arrangements of mechanism working on this principle are shown in Fig. 22. In the first one the water flows outward through curved, hollow arms fixed to a hollow shaft through which the water

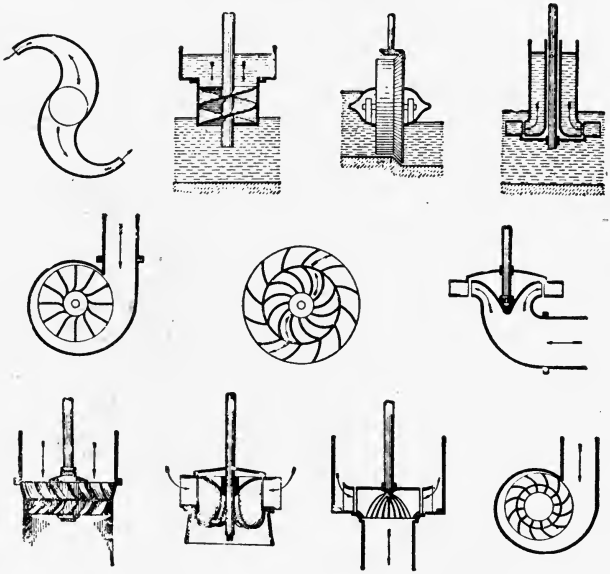

FIG. 22

is supplied, escaping from the outer edge or nozzle tangentially. The same action takes place but is less clearly seen in the other forms shown; the water is, however, conducted to the working vanes or nozzles in different ways. These passages are more often a continuous row of slots than single nozzles, for the purpose of getting as much push as possible around the circumference. To all wheels in which the reaction of the jet rather than the impulse of striking vanes exerts the driving force, the class name of reaction wheels is applied.

The antiquity of the reaction and impulse principles is shown by the records, in which it is said that one Hero, 200 B.C., or over two thousand years ago, made such a steam reaction turbine, shown in Fig. 23, in which a fantastic water vessel was heated by a fire, making steam which, flowing up two vertical standards, hollow, like pipes, entered a ball arranged to rotate on the ends of the standards. From the ball the steam escaped by nozzles tangentially, causing the ball to spin, to the mystification of the mass of the people, who believed that some spirit from the other world had been brought under command. A later, but nevertheless old, device, dating from 1629 and credited to Branca, an Italian, is shown in Fig. 24. This is a pure impulse steam-turbine, coupled by toothed gearing to a shaft with lumps on it arranged to lift the pestles for crushing corn or ore.

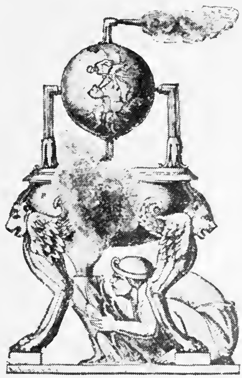

FIG. 23

The simplest, oldest, and at once the most modern ideas for power generation are, then: —

First, moving fluid properly directed may move wheels against resistance when it strikes vanes suitably formed.

Second, fluid under pressure may be made to acquire motion simply by escaping.

Third, jets of fluid escaping from nozzles or suitably formed passages in wheels may, by reaction of escape alone, turn those wheels.

To these principles minute and painstaking investigation, guided by progress in mathematics, mechanics, physics, and chemistry, which it no doubt assisted in

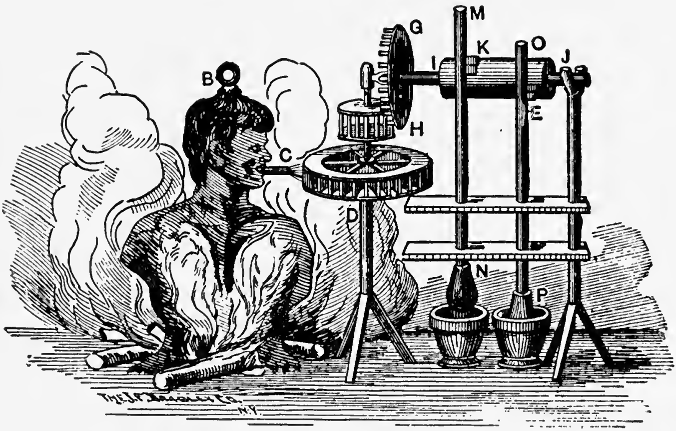

Fig. 24

stimulating as well, has added a vast body of principles of engineering, by means of which true design can be carried out, and turbines be built of predicted efficiency, of proper strength in all their parts, cheap and effective for all local situations.

While these three old principles of conversion of energy are all used in present-day turbine water-wheels and in steam-turbines, the idea underlying the more common form of steam-engine and that which may be said to have caused the industrial revolution referred to in the last lecture, the engine still most largely used on steamships and in factories and the sole dependence for locomotives, is different. It is this idea that also finds expression in all our gas, gasolene, and oil engines. This idea is based on the conception of fluid pressure as capable of exerting a push on pistons in cylinders. It was used, though not understood, by the savages, who made blow-guns, in which the hollow bamboo stick acts as a cylinder and the dart as piston; later also in powder-guns, where the gun-barrel is the cylinder and the projectile acts as piston. If a close-fitting but free-moving piston in such a cylinder be fixed to a rod, and water or steam under pressure be admitted to one end of the cylinder, the fluid pressure will push the piston if the other end of the cylinder be open, and so move the rod.

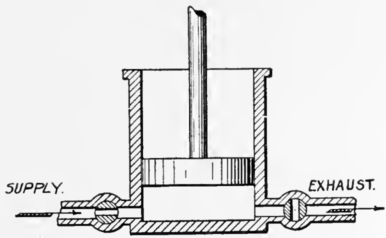

Fig. 25

When one end of the cylinder is open and the other closed for a working chamber, as in Fig. 25, and the closed end is fitted with two pipes, one for supplying steam, with a valve or cock to open and close communication between cylinder and supply, and the other for discharge, opening to the air, the cylinder is said to be single-acting. Closing both ends and passing the piston-rod through a close-fitting hole in one end requires the addition of another set of pipes and valves, and it is then called a double-acting cylinder, shown in Fig. 26. Two single-acting cylinders placed side by side, receiving steam from a boiler through one valve, are shown in Fig. 27, as built by Leopold in 1725, the up and down or reciprocating motion of the two piston rods working water-pumps, and the whole apparatus becomes a steam-pumping-engine. This early steam-pump uses steam at a pressure greater than the atmosphere, to push the piston to the top of the cylinder, after which the steam supply is cut off and communication with the air opened, allowing the steam to escape to the air as the weight of the piston forces it down.

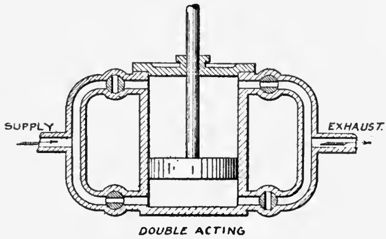

Fig. 26

This application of the pressure idea is not the oldest, nor was it as widely used in its own time as another one, in which the steam at a pressure about equal to the atmosphere was drawn into a cylinder, and there condensed or converted back to water by cooling, the resulting water of condensation occupying practically no volume compared with the steam. The best example of the old style engine

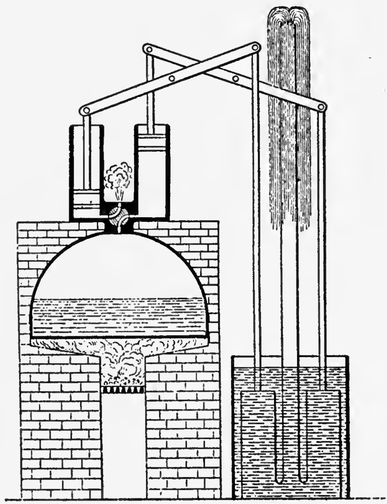
Fig. 27

using this idea is that of Newcomen, Fig. 28. This machine had a single-acting cylinder, and the piston-rod had a chain running over the curved end of a beam to compel the rod to move in a straight line, the other end of the beam having a weight sufficiently heavy to lift the piston, and draw into the cylinder steam from a sort of kettle having about atmospheric pressure, and, therefore, incapable of exerting any push on the piston, even when entering. At the top position of the piston the cylinder is full of steam which, having a pressure equal to the atmosphere acting on the outside of the piston, has no tendency to move the piston one way or the other. Closing the steam supply valve and opening a valve in a water pipe between an elevated tank and the cylinder allows water to flow into the cylinder containing the steam, which is thereby condensed. The pressure at once falls in the cylinder to a value less than that of the atmosphere acting on the outside of the piston, the lowered pressure being called a vacuum. This vacuum, or deficiency of pressure within the cylinder below that of the atmosphere outside, allows the atmosphere to press down on the piston, moving it, with the rod, beam, and counterweight, back

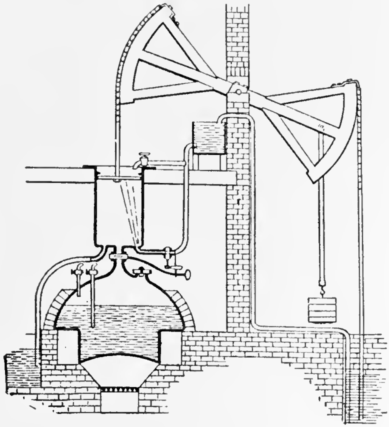

Fig. 28

to the starting-point. The motion against resistance is, therefore, produced solely by the atmospheric pressure. There are many familiar illustrations of this vacuum and atmospheric pressure action, commonly called suction; the ordinary act of drawing water into the mouth in drinking is a mild case, the muscular movement of the cheeks and chest producing a pressure in the mouth slightly less than that of the atmosphere, which forces the water inward. A still stronger suction or vacuum is required in drinking through a straw and in filling a syringe, while the ordinary barometer which measures the atmospheric pressure is only a vertical tube of mercury dipping into a cup at the bottom with a vacuum at its closed top. It is known that the most perfect vacuum resulting from the pumping out of a glass bulb all the air it contained will enable it to suck water, as we say ordinarily, or more properly enable the surrounding atmosphere to push up water into it, through pipes from a level not more than thirty-four feet below it at sea level, which is equivalent to a pressure of 14.7 pounds on each square inch of surface. If, then, water be led into a vacuum chamber with an open pipe extending downward thirty-three feet or more into water, it would not fill the chamber but would run out, keeping the level always the same. This engine of Newcomen, which was used first in 1705 and continued at work in some places for seventy years, not only operated primarily on the vacuum, as engineers would say, or by atmospheric pressure, to be more scientific, but had a long pipe from the cylinder to allow the injected water and condensed steam to escape without assistance and automatically.

While Newcomen in his condensing atmospheric engine made use of the excess of atmospheric pressure over that of the vacuum produced by condensing steam, and Leopold made use of the excess of steam pressure over atmosphere, to do work in single-acting engines, James Watt combined the two pressure actions, getting as a result a double effect in his engine of 1784. This engine, shown in Fig. 29, marked the beginning of the building of steam-engines using the idea of pressure acting on a reciprocating piston, with mechanism to change reciprocating motion into the desired rotary motion, always under control. In it were incorporated ideas basal to the modern locomotive, the standard horizontal and vertical engines for electric light, street railway, and factory power stations, the modern pumping-engines for city waterworks, the blowing-engine for supplying air to blast furnaces which extract iron from the ore, and a host of others, in almost infinite variety of detail in each of the several classes. Each of these, while having the essential pistons in cylinders, and cranks to give the rotary motion, valves and governors to control the steam, and all supplied with steam made

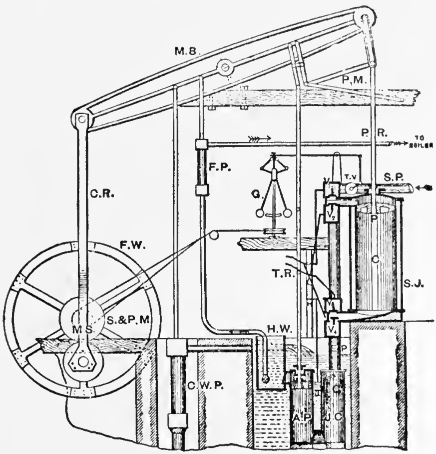

FIG. 29

in separate boilers from the combustion of fuel, yet has differences of structure and arrangement of parts, developed as time showed the necessity, to adapt the common essential elements to the special service. Thus, the locomotive of Fig. 30, in which the construction is clear, must contain all the elements of a complete plant supported on one frame, with as much weight on the driving wheels as possible to give adhesion. The whole machine must be rugged to stand the pounding

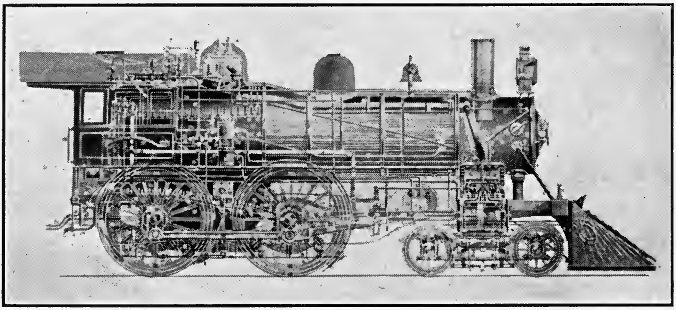

Fig. 30

on the rails, so all delicate mechanism must be avoided. It must be reversible, so mechanism is introduced to shift the valves by hand in addition to their normal automatic movement, and so on. The marine engine, which drives the ship, must be fairly well balanced and turn regularly without jerks, so as not to shake the ship, so that several cylinders, each with its own crank, are set side by side and the cranks set at different angles; it must also have a light frame, so as not to reduce the carrying capacity of the vessel. This construction is well shown in Fig. 31, illustrating the engines of the United States battleship *Vermont* in the

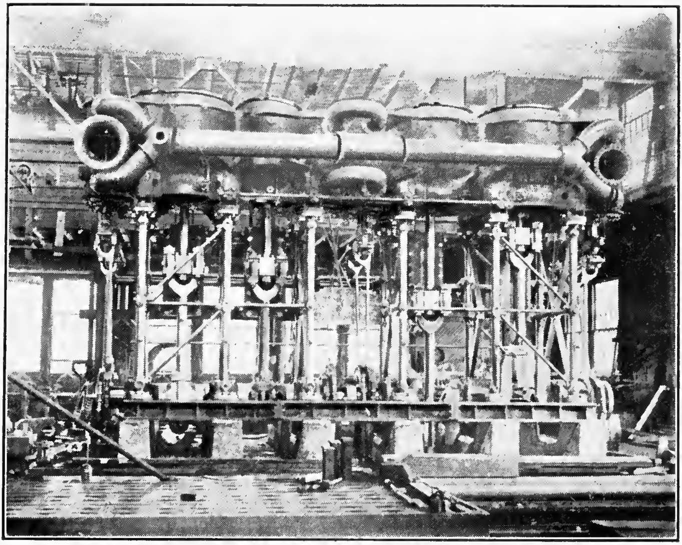

Fig. 31

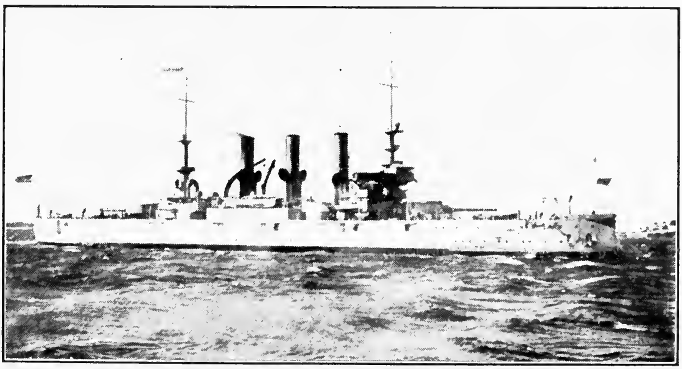

Fig. 32

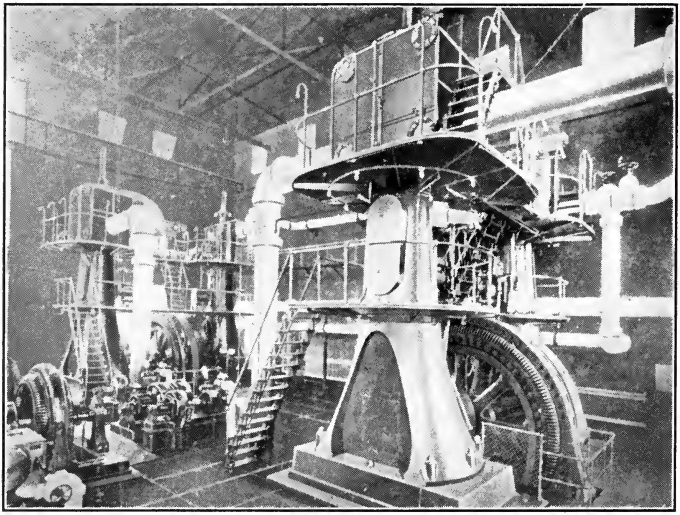

FIG. 33

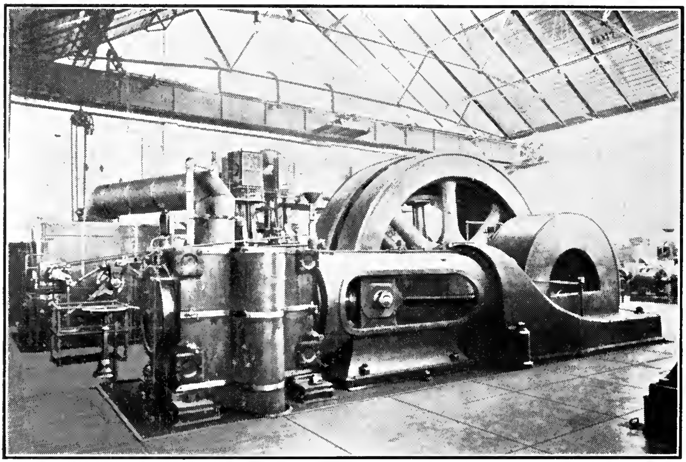

FIG. 34

shop of the Fore River Ship Building Co., Fore River, Massachusetts. The vessel herself is shown in Fig. 32. Questions of weight are of little importance in stationary engines compared with steadiness and durability, but sometimes floor space is valuable, in which case a vertical engine of fairly heavy construction, such as

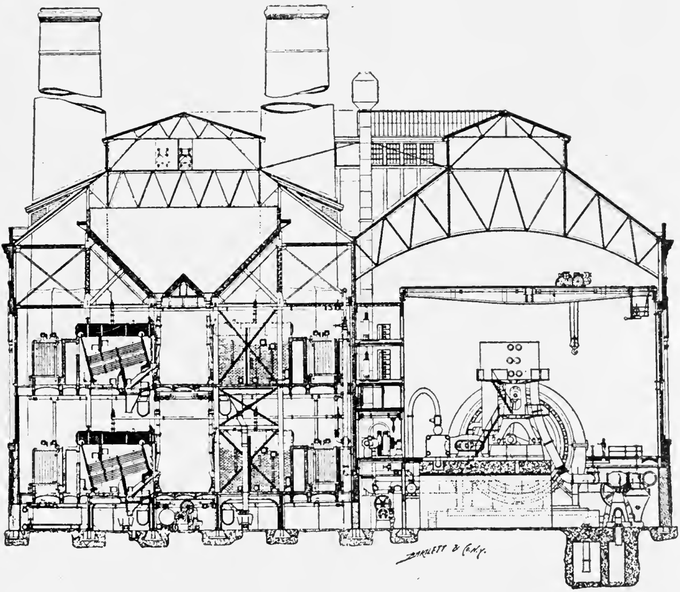

FIG. 35

shown in Fig. 33, is suitable. These engines drive the factory of Walter Baker Co. at Dorchester, Massachusetts, by electricity, the engines themselves driving electric generators, the current from which is transmitted through the factory to motors which do the work. When floor space is not valuable, the annoyance of stair climbing to reach high parts that need oiling can be eliminated and horizontal engines, such as shown in Fig. 34, substituted. The relation of engines and boilers in a large stationary electric plant, having combined vertical and horizontal piston engines, is well shown in Fig. 35, which is a cross-section of the Manhattan Elevated Railroad plant, as originally built, having a capacity of 50,000 h. p. It should be

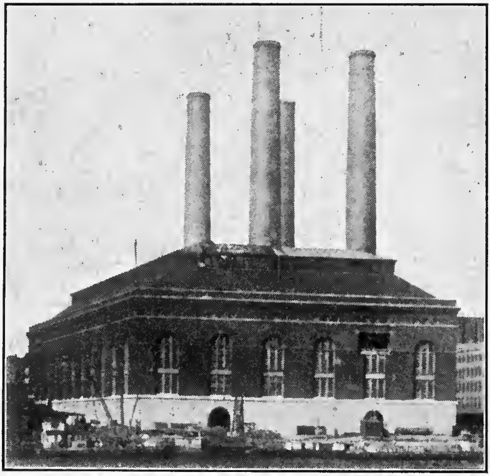

FIG. 36

noted that the boilers are located on two stories to economize real estate, which is valuable, and the coal storage bins are placed just under the roof. Water for the condensers, located in the basement of the engine room, is supplied through tunnels leading to the river. The external appearance of the power station is shown in Fig. 36.

Two special classes of piston steam-engines, one for pumping water and the other for compressing air, and therefore called pumping-engines and blowing-engines, are shown in Figs. 37 and 38. The former illustrates one of five Allis-Chalmers pumping-engines, for the Hackensack Water Company at New Milford, New Jersey, having an aggregate capacity of 72,000,000

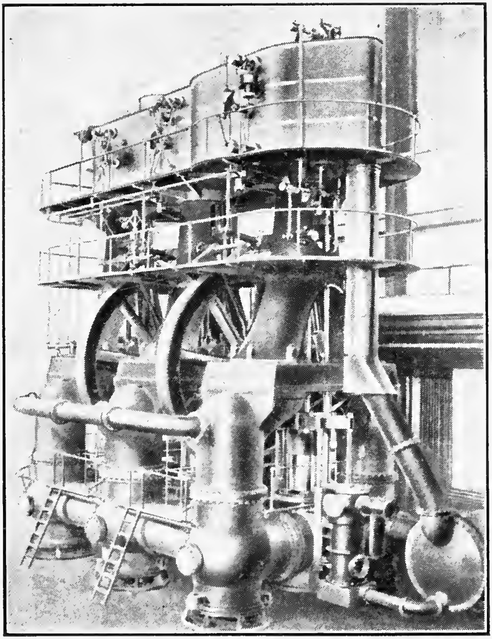

Fig. 37

gallons of water in twenty-four hours. The latter (Fig. 38) is a blowing-engine with a capacity of 30,000 cubic feet of air per minute at 30 pounds pressure, for the furnaces of the Republic Iron and Steel Co., and its great size is shown by comparing it with the man at the side.

To produce motion of an engine shaft from natural forms of energy, it has been shown that the first step is to so supply that energy as to get some fluid under pressure, if it is not so originally, and then to use that high-pressure fluid either to push on pistons or give itself a velocity by escaping from a nozzle, the jet impinging on vanes or reacting on the nozzle. This

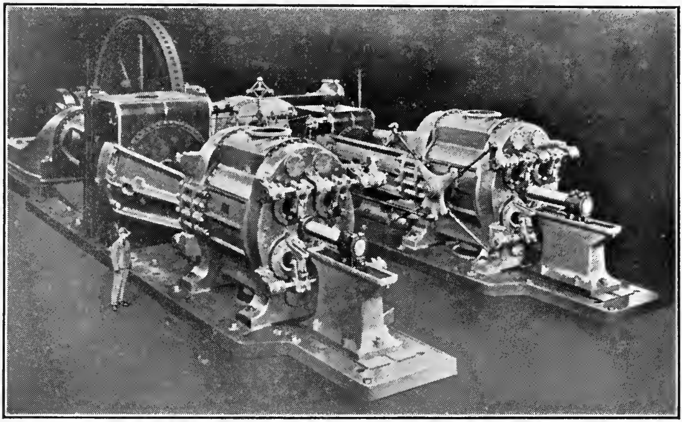

FIG. 38

is true no matter how the fluid acquires the pressure. In the water-power system advantage is taken of rivers in a hill country, and dams are constructed when necessary to collect rainfall and store water for use in dry seasons at a high level, and pipes are connected to conduct the water to a low level, at which point a pressure supply becomes available. On the other hand, in the steam system the pressure is produced by burning fuel under a boiler; while in the gas-power system, not yet examined, the pressure is produced by explosion within the cylinder itself, and the action of the hot high-pressure gases that result from it is always by direct pressure of these gases on a piston. Curiously enough, however, the high pressures obtainable by explosions of suitably prepared fuel were not at first directly used, but instead the heat of the combustion was made the means of getting the atmospheric pressure to act, just as the atmospheric steam-engine preceded that using high-pressure steam. In 1860 Huygens exploded gunpowder in a cylinder having a piston, the hot gases escaping from the cylinder through open valves which were closed as soon as the internal pressure equaled that of the atmosphere; then the hot gases were cooled and in cooling lost pressure, producing a partial vacuum exactly as did the condensing of steam in Newcomen's cylinder. Atmospheric pressure forces the piston inward, giving motion, from the combustion of fuel directly without any steam intervention, but the effect is feeble and no successful gas-engine would ever have been built if study had stopped there. It required a lot of time to connect the idea of the common gun, using high gas pressure from the explosion of solid gunpowder fuel, with the piston engine idea. It did not come about until the realization that combustible gases mixed with air would produce an explosion resulting in high pressure, that could be used to act on a piston, and which could be controlled quite as well as steam. It is probable that the old notion of explosion being connected with destruction had a good deal to do with the delay. After a series of proposals dealing with explosive gas and air mixtures, beginning about 1825, there finally was produced, but not before

1860, an operative gas-engine, by Lenoir, a Frenchman. This engine had a cylinder and piston with the usual rods, cranks, and shafts that had had at this time nearly a century of service in steam-engines. The cylinder (Fig. 39) is fitted with valves on one side through which the piston may suck in air and gas in suitable proportions, after which the valve is closed and the mixture ignited by an electric spark, which causes an explosion, the high-pressure gases from which drive the piston forward. On the return stroke the burnt gases are pushed out through a valve on the other side. The general appearance of the engine is shown in Fig. 40. While the engine was a commercial failure, it nevertheless was the beginning of a development which has resulted in the production of the most economical fuel-burning power system the world has ever seen, the prime element of which is the gas-engine itself, in which suitably prepared gaseous mixtures are exploded directly in the working cylinders. The first large installation of gas-engines in this country, made at the Lackawanna Steel Co., consisted of 40,000 h. p., some of which drive electric generators, as shown in the upper part of Fig. 41, while the rest drive blowing cylinders, as shown in the lower half of the picture.

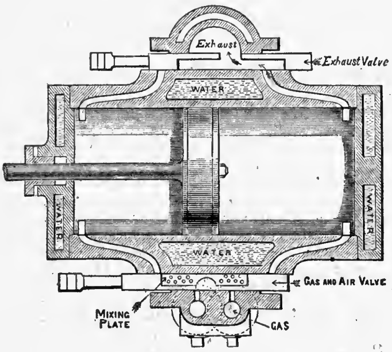

FIG. 39

It is a most significant fact that although Hero produced a rotative steam-engine, that worked, in 200 B.C., nearly two thousand years elapsed before the first commercial rotative steam-engine was produced by Watt, about 1780, and that after him the progress of about seventy years in power-system development resulted in advances entirely eclipsed by progress since that time. There are good reasons for these things, and the key is to be found, first, in the lack of demand; second, in the lack of information to enable makers of

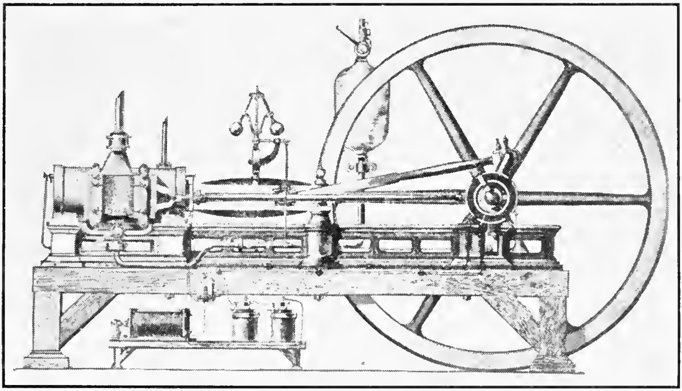

FIG. 40

machinery to meet demand when it came. Practically all the power machinery produced before the time of Watt, in 1780, except special devices adapted to pump water only, was more the result of accident than of logical reasoning from desired results to means by which they might be attained. Even after Watt much that was done was prompted more by a desire to do something different, a groping after something by trying everything. There was no conviction based on

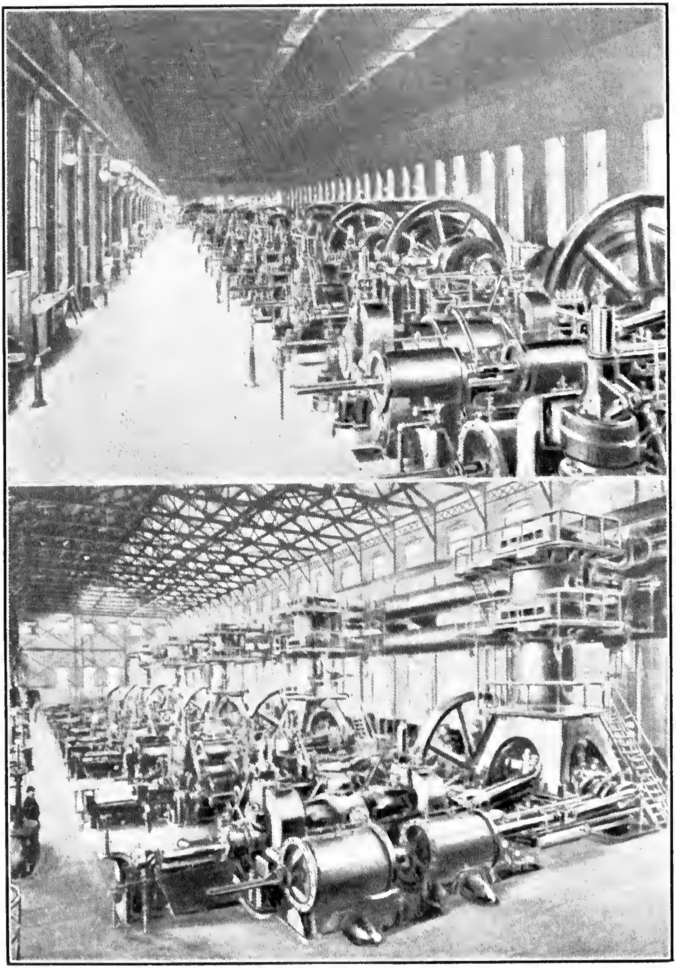

Fig. 41

proof or on established principles that the means were right or best. This was pure invention, without which, it is true, little progress is possible; but true progress based on a conception that the new thing proposed must and will produce the desired result in a truly better way, or produce a new result superior to the old with no more wasteful means, becomes possible only when there is available a body of facts and principles related to each other. Such a body of related facts and general principles constitutes a science, by means of which existing machinery can be analyzed to reveal all its faults and their causes, and the performance of new machinery yet unbuilt can be predicted with reasonable certainty. This latter proceeding is true design, without which invention alone may result in nothing more than interesting toys, but which when combined with invention gives the engineer whose business it is to do these things his command over nature. The basis of engineering design is knowledge of facts and principles, so that it is easy to understand why in the early days of engine building no true design was possible; for the machine and its processes in operation themselves supply the means for collecting the necessary facts, and mental capacity, however well trained to the work, cannot find the relation between the facts until the facts themselves are found by tests of the machinery already built. Once discovered and classified, these relations constitute a body of principles having the force and dignity of laws of nature, the discoveries and application of which to the uses of men constitute the profession of engineering. The slowness with which all this developed can best be explained by lack of demand.

Up to the time of Watt nobody seemed to have any use for rotating shafts except to grind grain into flour, and perhaps to pound a little ore, or blow the bellows of an iron furnace. The conditions of living were very simple. Most of the people lived in the country, each family producing for itself by hand labor and horses the necessaries of life, the men plowing and reaping, the women spinning thread from the wool of sheep raised on the farm, and both men and women weaving thread into cloth for their own clothing during the winter months. Simple tools were used, such as the hoe, flail, plow, spinning-wheel, and hand loom, but there were some elementary machines, such as the stones for grinding or polishing, driven by simple and small windmills and water-wheels, or by horses.

There were no large cities, but a good many villages, which developed principally at seaports or on rivers where sailing vessels called and where, as a consequence, the commercial and trading elements of the population congregated. Inland towns were principally headquarters for the wagon and stage-coach, or trading centers, the location of the markets or fairs where, at stated intervals, farmers exchanged those things of which they produced more than they needed with others within driving distance who produced other articles in like excess. There was also a regular travel to and from the mills, located principally on river dams or at falls, and these were the nearest approach to power manufacturing as we understand it. There was, however, some other manufacturing, mainly of the concentrated hand craft or trade order, such as would result when one man would buy wool, employ a number of hand spinners, and sell yarn and thread, or buy these and by more or less regularly employed weavers make cloth to sell.

The most important manufacture, such as it was, was of woolens, and these constituted one-quarter of the total export of England. Next to woolens were iron and iron goods, which employed in all their branches about two hundred thousand persons. There were also some pottery, hardware, and cutlery, and about thirty thousand people engaged in making brass and copper things, also a little silk, hosiery, and glass, all produced without power.

It was not until after a series of inventions in spinning and weaving resulted in machines that required power that the change of conditions began. This series of inventions began in about 1738, when Kay invented the fly-shuttle, to carry the thread across and back in weaving, and enabled one hand weaver to do the work of two, thus doubling the demand of weavers for thread and stimulating the spinners to catch up. Then Hargreaves made a spinning machine that increased eight times the capacity of the spinner, thus producing more thread than the weavers could use, which was followed by future improvements in spinning by Arkwright in 1768 and Crompton in 1779, just about Watt's time. This great advance in spinning by machinery was all the stimulus needed to similarly develop the power loom, perfected by Dr. Cartwright in 1787, when Watt was building steam-engines for sale. These Watt engines were put into textile factories, which could be located wherever most convenient to supplies of coal, or raw material, and were not limited to waterfalls on rivers. Thus it was demonstrated that power could be produced from coal and cheaper than in any other way, and could successfully operate manufacturing machinery in factories. The power machinery worked reliably and well, maintaining the regular, steady speed needed to prevent the breaking of fine threads, and directed the attention of everybody to devising other ways of doing their work, or making things by machinery, that would permit the use of these engines. One of the most important industries to which power machinery greatly contributed, and curiously enough one on which it was also very largely dependent, was the iron industry. By machinery ore, limestone, and fuel are supplied to tall furnaces and air blown in, originally from bellows; the steam-engine was applied to Smeaton's cylinder blower within ten years; while a few years before, the plan of driving large cold iron rollers by the engine, to squeeze lumps of red-hot iron into bars of useful shapes and improving the toughness of the metal, had been adopted, thus improving the quality of metal with which to build machines, greatly increasing the output to meet the new demand, and at once cheapening the product. These cases are cited merely as illustrations of the almost immediate world-wide interest in machinery of all kinds to use power.

It is impossible here to examine all the modifications of power apparatus adapted to various applications, but it is most interesting and instructive to notice how slow men's minds work with new ideas, as demonstrated by the long time it took to take, what now seems obvious, the steps of applying Watt's successful engine to locomotives and steamboats. Although the Romans are reported to have used paddle-wheel boats driven by horses and oxen, yet it was not until twenty-seven years after Watt's steam-engine that Fulton produced the first commercially successful steamboat, using an engine that he bought complete from Watt; and not until 1829, about fifty years after Watt, that Stephenson produced the first commercially successful locomotive, "The Rocket." These long lapses of time for so simple a thing as the adaptation of a successful rotative steam-engine to the moving of the paddles of a steamboat, and to driving the wheels of a locomotive, are most significant, and doubly so when it is remembered that both the *Clermont* and the "Rocket" were built on the collective ideas of many preceding years of trial. Even these two productions, Stephenson's locomotive, the "Rocket," and Fulton's steamboat, the *Clermont*, were extremely crude affairs, as will appear on comparing Fig. 42, the "Rocket," with the modern locomotive that we know, and by comparing Fulton's *Clermont* (Fig. 43) with the modern river- and ocean-going boats (Fig. 44).

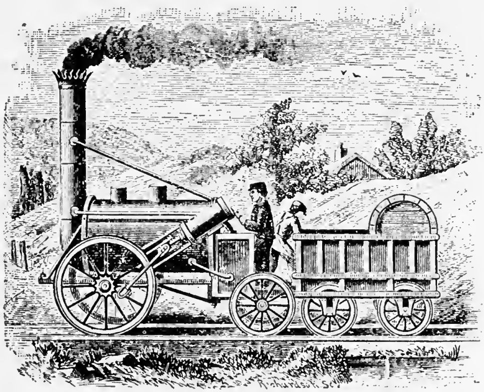

Fig. 42

No one can fail to be impressed with the enormous differences between the old and the new power machinery, but this comparison cannot begin to teach a lesson of value anywhere near proportional to that which follows a study of the ideas underlying the change, or their ultimate consequences. The machines, as assemblages of working parts, each with duties to perform, are but the outward and visible sign of principles discovered and classified into a body of science that can never change except by additions, and which is the inheritance of our children, who may come to realize the potency of these invisible tools by studying the industrial, social, and economic results that have followed their use in the past. Great as have been the consequences of the use of power and machinery, still greater, though less easily grasped, is the contribution to the develop-

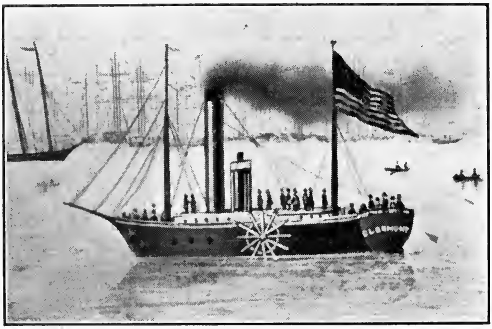

Fig. 43

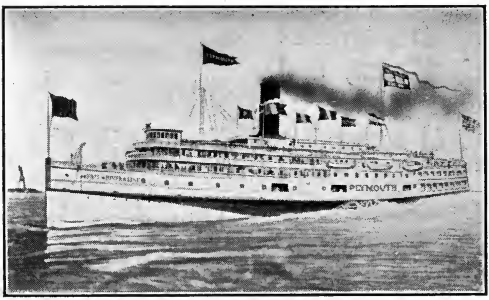

Fig. 44

ment of the natural sciences, which are to-day so firmly established on unassailable foundations that future development will have a guide as trustworthy as the compass to the ship, pointing out clearly and positively the place where effort is to be exerted, in striking contrast to the methods of blind groping and wild guessing that characterized these early stages which, even so, were able to precipitate an industrial revolution. Mathematics, mechanics, physics, and chemistry have become what they are in this intermediate period. The laws governing the strength and formation of structures have been discovered and codified in the modern theory of elasticity applied to the materials of construction. The nature of heat and its relation to work were found out only toward the end of the period; but the basal conception, once reached, soon grew and produced others, until there appeared that body of principles called Thermodynamics, inclusive of all forms of energy, showing not only the essential equivalence of heat, work, light, electricity, and magnetism, but also revealing the laws governing the conversion of one form into another.

Applications of these sciences, assisted by the modern methods of producing suitable materials and working them into appropriate shapes by the tools and systems now prevailing in our shops, are daily producing results as wonderful as anything that Watt, Stephenson, or Fulton ever did. But as these productions are daily occurrences and not easily understood by the mass of the people, the names of these men working out of sight in shops and factories will probably never be handed down to posterity.

III

ESSENTIAL ELEMENTS OF STEAM-POWER SYSTEMS

All steam-power systems, whether designed for land or marine transportation or the stationary generation of power contain the same essential or primary elements for obtaining motion from steam under pressure. But besides these essential elements there are hundreds, yes, even thousands, of other parts, each put in place for a definite purpose, which may be generalized under the heading of better or more efficient service under some special local condition. Even the essential elements, similar as they are, do themselves differ vastly in detail, generally with good reason, but, of course, sometimes without. Because of the greater variety and inclusive nature of the steam-power machinery designed for stationary work, principal attention will be directed toward this, but not so much for the purpose of demonstrating the variations in details as to indicate the principles that, once established, lead to these forms, which are, truly, ideas clothed in metal.

The essential ements of a plant whose purpose is the generation of power from fuel by the steam system are: first, a steam-generating part, and second, a part to use that steam. The first part must make as much steam as possible with a pound of coal, and the second must do as much work as possible with a pound of steam. The steam-generating equipment will consist of a boiler with means for feeding it with water and supplying it with coal, a furnace adapted to burn that coal, a flue to carry off the gases of combustion, containing a damper to regulate the fire, and hence the rate of steam making, and means for creating the draft by which the furnace is supplied with air, together with certain other trimmings or accessories such as glass tubes for showing the water-level, safety-valves for preventing the pressure rising too high, and connections for removing sediment that may collect. The steam-using equipment will include the engine proper and means for conducting the steam by piping from boiler to engine and from engine to the air, or condenser if one is used. These piping systems are oftentimes extremely complicated, especially when many engines and many boilers are connected together and these are located on different floors of the same building. In some plants there are as many as sixty large boilers under one roof. The engine proper consists essentially of either a piston and cylinder with valves to admit and exhaust the steam, or nozzles and vane wheels, together with mechanism to regulate speed, lubricate bearings, permit of adjustment of wearing parts, and prevent the leaking of steam from joints. For stationary purposes alone there are available to-day on the American market hundreds of different boilers, and hundreds of different engines, even of the same size, and a great range of sizes, from a fraction of a horse-power up to approximately thirty thousand. These large engines are confined to the largest plants, are seldom used singly, and are always supplied by a larger number of boilers, that have a horse-power capacity seldom exceeding 500 and in a few cases 1000 h. p. each, so that in the large power stations one may expect a few large engines and a great many small boilers. It has been found by experience that the larger a steam-engine, other things being equal, the less steam it will consume in an hour to maintain the horse-power. This is the reason why a few large engines in places where there is a great demand for power have supplanted a larger number of smaller ones. But this concentration to get better steam economy cannot be carried too far, because any engine unless it is working somewhere near its capacity is wasteful of steam, and at certain times of the day or certain seasons of the year the demand for power is less than at other times.

If there were just one engine in a large power station, it would be wasteful of steam during the time of smaller demand, however economical it might be during those times when the demand is about equal to that for which it was designed. On the contrary, with boilers there appears to be little change in the economy of the different sizes, and it is more convenient to fit into available spaces and to maintain many small boilers than a few large ones.

The controlling idea not only in plant construction and operation, but in the selection and form of every single part, is in every case economy — economy not only of coal alone, but of everything taken together, each at its proper value, not forgetting suitable service; and curiously enough it appears that some of these conditions are contradictory. For example, if space be valuable, as it is in torpedo boats, the boiler must be made light, and then it is difficult to make it economical. Similarly, if the engine must be highly economical, it will invariably cost more to make than one less economical. When the service is to be temporary only, a small first cost is warranted. When labor is difficult to secure or the place of operation dirty, then there must be a minimum of complication and no delicate parts; when fuel is expensive, then the investment for machines may be properly high if coal can be saved thereby, but the apparatus may become complicated and require much skilled attention, the cost of which may overbalance the coal saved. These different conditions and many others not noted have contributed to the development of the variety of form in engines, boilers, and auxiliary equipment now in existence. Every separate case of power requirement must be studied to find the controlling condition, which, when satisfied, would yield the power with the least all-round cost; and the determination of this is a problem more difficult to solve than that which Watt had to meet when he tried to produce the first rotative steam-engine.

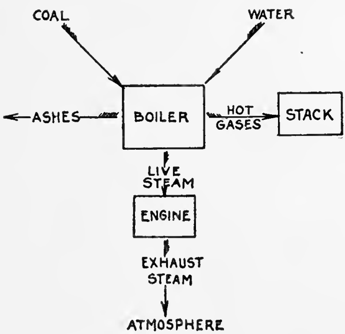

Fig. 45

The general relations of the boiler to the supply and delivery of the necessary substances are shown in Fig. 45. It is supplied with three things, — coal and water and, of course, air; and discharges three things, — ashes, which must be removed, hot gases, which go generally to a stack or chimney, and live steam or steam under high pressure, which goes to the engine, and to the various pumps and auxiliary appliances, not shown.

It would seem that there should be no difficulty in constructing a vessel in which to boil water to make steam, and yet there is no more difficult problem for the engineer to solve, when there is added the condition

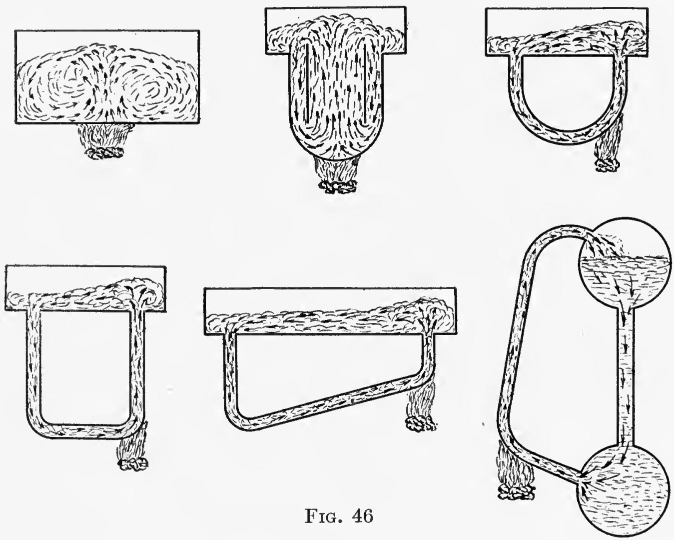

Fig. 46

that the boiler must be as economical, as small, or as durable as possible, and otherwise adapted to the multitude of different conditions under which it has to work. Consider a plain tank, as shown in Fig. 46, at the upper left, with heat applied to the center of the bottom. The water heated immediately over the fire rises partly because it is a little lighter than the rest of the water and partly by reason of the steam bubbles; the rest, or colder water, will come down around the sides. This movement of water is called convection, and indicates that whenever a mass of water is unequally heated there will be currents set up. These currents in boilers give what is known as circulation, or an automatic flow from one part of the chamber to another, and boilers are designed so as to promote and make use of this circulation, and care is exercised in fixing the form of boiler and the location of the fire to avoid any interference with it. The next form of vessel, which has an open tube submerged in the water, will permit of more violent boiling with less surface agitation because the currents are guided by the central tube. In the third, fourth, and fifth forms shown, there is a U-shaped tube element in which water is heated more on one side than the other. It will rise in that side and fall in the other, but may be made to flow either way by changes in the point of application of the heat. When, however, the construction is such as is shown last, the water can flow only one way because the top of the circulation tube is above the water-level. Recognition of these principles of circulation, the discovery of which took a long time in the boiler development, is now considered quite essential to the making of good boilers of small size yet capable of yielding great quantities of steam without moisture. The earliest boilers were just plain tanks set over grates, with flues running under them and along the sides, so as to keep the hot gases in contact with the shell long enough for them to give up their heat to the water. It did not take long to discover that in order to make very much steam the tanks would have to be pretty large, and there are cases reported in which these tank boilers were 40 feet or 50 feet long for only a few hundred horse-power, a condition quite impossible when the cost of making them is considered, together with the floor space they would occupy. To reduce the size and still present

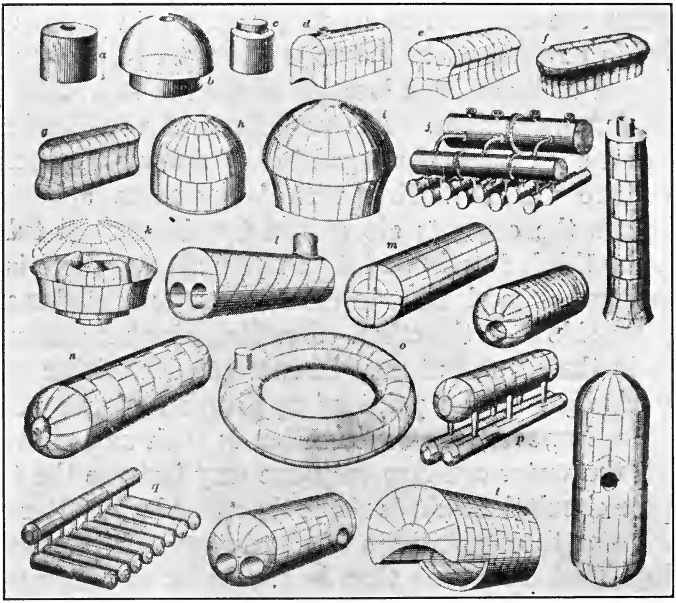

FIG. 47

enough surface of contact to the hot gases, large tubes, or flues as they were called, were introduced into plain shells, and all sorts of queer shapes of shells tried, some of which are shown in Fig. 47. The use of high pressures, necessary for economical use of steam in engines, forbids irregular forms of shells, as they burst too easily, so that from the time high pressures came into use we find nothing but cylindrical shells with flues or tubes. One of the early flue boilers with its brick setting is shown in Fig. 48. In this form the grate is under one end, and the gases having passed down under the boiler return to the front again through the flue. In another case, however, fire is made to pass in the flues down through the center, discharging back along the sides. Modification of these flues by reduction of the diameter makes them tubes and very materially increases the heating surface and steaming capacity for the same size shell, and such a construction constitutes the modern horizontal return tubular boiler, which is to-day the most widely used type of stationary boiler. This boiler consists of a plain, cylindrical shell, much the same as shown in Fig. 48, but with many tubes two to four inches in diameter packed in its lower part, through which the hot gases return to the front, after having passed from front to back under the bottom. Shell and grate are built in brickwork settings. It has been found necessary in marine service to avoid brick settings, and this condition is met by using in the lower half of the boilers large flues containing the fire, the gases passing to the back and returning through a bank of tubes in the upper part of the shell, and this construction is that of the so-called Scotch boiler, as

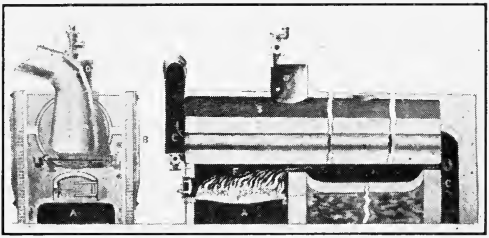

Fig. 48

shown in Fig. 49, the most widely used boiler on steamships. It should be noted how all flat surfaces on which the pressure acts are braced to prevent bulging. A

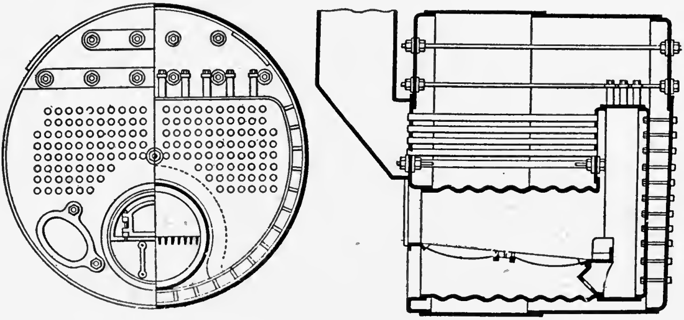

FIG. 49

sort of intermediate type of boiler, adapted for locomotives, is shown in Fig. 50, in which one end of the boiler is made square, to form a fire-box of metal plates surrounded by water; from the fire-box the gases pass

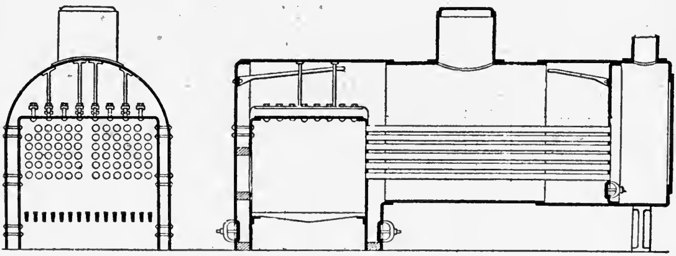

FIG. 50

through straight tubes to the stack in front. With minor modifications this is almost the universally used type for locomotives, its form being well adapted to fit on the frame above the wheels. In these three classes of boilers shown the gases pass through the tubes and they are, therefore, known as fire-tube boilers; and in some of them, as the Scotch marine and the locomotive, the fire is also within the boiler, and they are said to be internally fired.

In all of these fire-tube boilers the circulation is not considered as effective as it might be. In general the

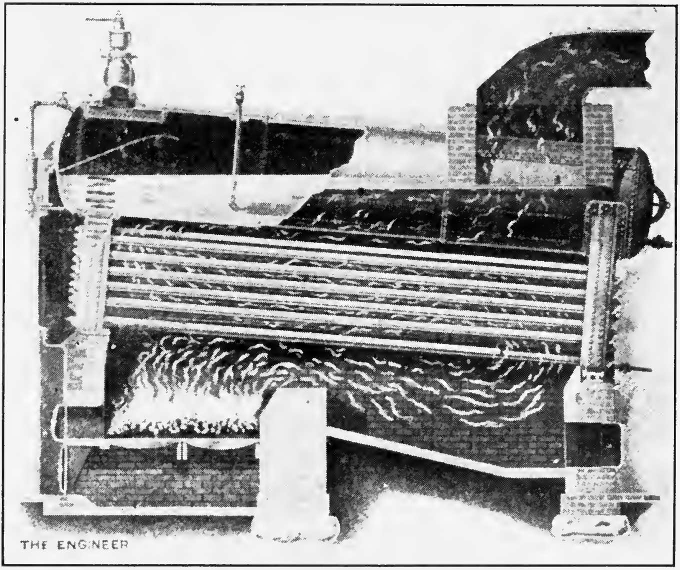

Fig. 51

water is rising from all the hot tubes, the steam bubbles escaping from the surface of the water all over the center of the top. The water thus carried up by the bubbling forms a sort of a hill in the middle, or perhaps concentrated toward one end, from which the water runs down the sides of the shell or the other end, back to the bottom, to supply the tubes from which the steam has escaped. With a view largely to improving the circulation, but for other reasons as well, a different type of boiler has been developed, principally in recent years, known as the water-tube type. In its horizontal form, as shown in Fig. 51, it consists of a top drum with two narrow, flat boxes extending downward from it, one at

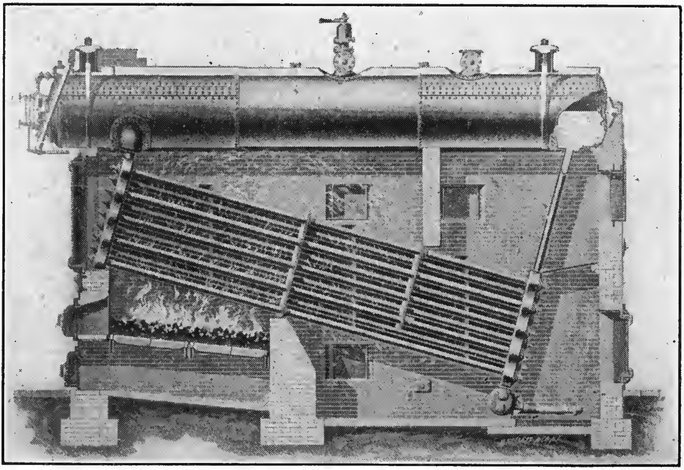

Fig. 52

each end, and a bank of inclined tubes connecting these approximately vertical, narrow boxes, which are termed "water headers." Water rests in the lower third of the drum and fills all the tubes and headers, and as the heated tubes are inclined upward toward the front, the water is forced to rise through the front header, discharge its steam, and descend through the rear header back to the hot tubes. To insure sufficient activity of all the tubes, tiles are placed between them, making baffles which direct the gases from the fire backward, forward, and finally backward. This type of the so-called horizontal water-tube boiler is built up of straight tubes, which are more easily cleaned than curved ones. It must be remembered that all water used in boilers contains dissolved salts, which, by the continuous boiling away of the water, are left behind in a solid state.

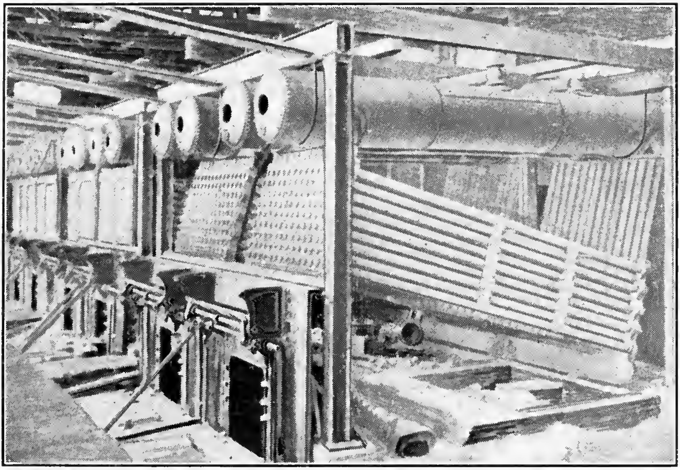

FIG. 53

This solid matter collects in two ways: first, as loose sediment or mud which can be easily blown out; and second, as a hard layer of stonelike scale sticking to all the surface where the boiling is taking place and interfering with the flow of heat through the tubes. When tubes are straight, as they are in this boiler, and holes provided with cover caps in the headers, scrapers can be run through them to knock the scale off, an operation which is practically impossible with some other constructions. Another one of these horizontal water-tube boilers is shown in Fig. 52 with a different system of baffling. Here, instead of a tiled roof laid over the bottom row of tubes directing the gases backward, they are forced to rise at once, then fall, and finally rise, crossing the tube bank three times. In Fig. 53 there is shown a row of these horizontal water-tube boilers in course of erection at the Pacolet Mills, Gainesville, Georgia, which will serve to make clear the construction, and its relation to the brick inclosing setting. When there is plenty of head room or a shortage of floor space, a different structure of boiler may be used. To meet this condition the vertical water-tube boiler in a variety of forms has been designed and is much used, for example, by the large steel mills, in which will be found dozens of them set in one row. One of these vertical boilers is shown in Fig. 54, consisting of a bank of straight tubes between two drums, the top drum having a hole in it for the discharge of gases, the whole structure being surrounded by brickwork; the furnace, also of brick, is separate and placed to one side. A group of these boilers in

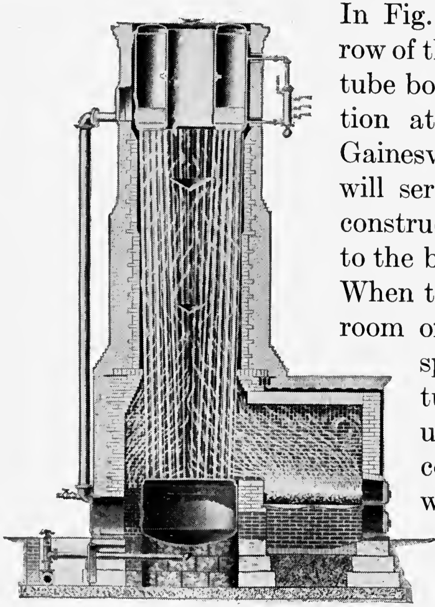

Fig. 54

course of erection at the Lowell and Suburban Traction Company's power house at Lowell, Massachusetts, is shown in Fig. 55, in which the mason building the brick walls can be seen at work standing in the furnace space and by whom the size of the structure can be judged.

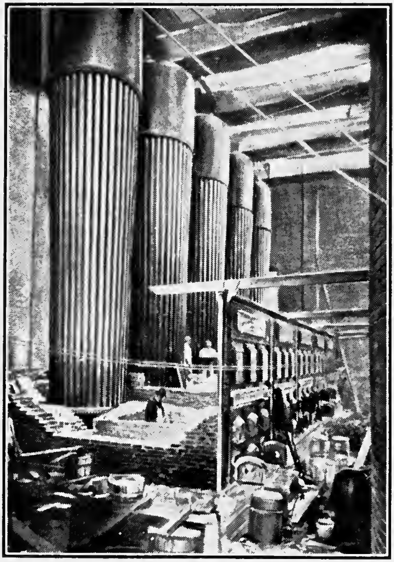

Fig. 55

There have also been developed a number of curved-tube type boilers, the construction of which has been prompted by a desire to get into a given space as much tube surface as can be properly arranged in reference to the flow of the gases, and at the same time promote vigorous and positive circulation. One of these, with the tubes only slightly curved, and the principal curvature given to those tubes in which the tendency to form scale is least, is shown in Fig. 56. In this system there are three top drums and one bottom drum, all connected by tubes and set in brickwork with baffles arranged between the tubes to cause the gases to flow first up and then down and finally up, passing out through a damper to the flue stack at the top of the back. This makes three banks of tubes. Through

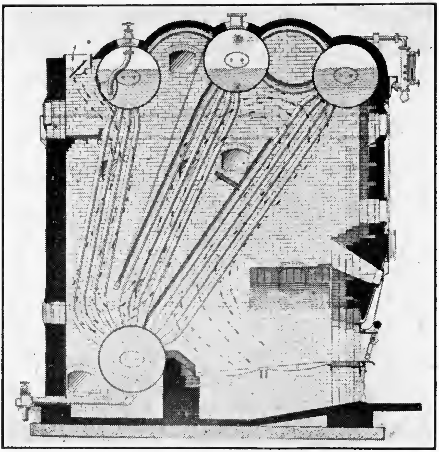

Fig. 56

the first two, water and steam together are rising under the intense heat of the fire, and the water that separates out from the steam in the two front drums runs to the back drum, and then down through the back tubes to the bottom drum, returning upward again. To show more clearly the construction there is added Fig. 57, showing a row of these boilers in the course of erection and in various stages of completion at the St. Clair Steel Co., Clairton, Pennsylvania.

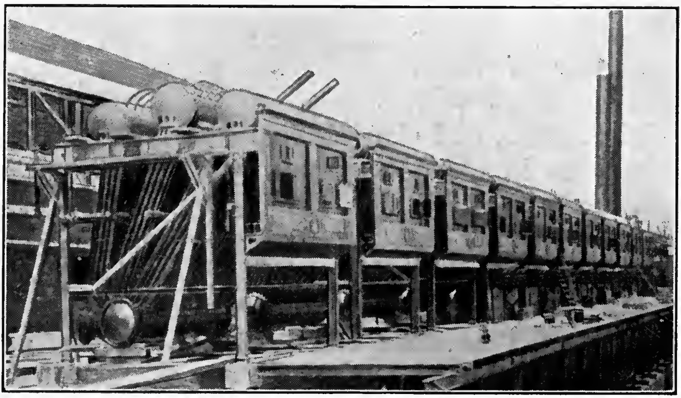

Fig. 57

Perhaps the most severe conditions of space and weight conservation are found in steamships intended to go at high speeds. Both fire-tube and water-tube boilers are used; an example of the fire-tube type has already been shown in connection with the *Kaiser Wilhelm.* The water-tube class is represented by several different forms, some straight tube and others curved tube; the curved tube, however, being mainly confined to torpedo boats, where the conditions are most severe with regard to space and weight limitation. In every case these marine boilers have grates underneath the entire boiler. No brickwork is used because of its weight, the boiler being inclosed by sheet metal and layers of non-conducting material. Special attention is paid to circulation, and the same principles are followed as in land practice. One special form that has been developed for this service is shown in Fig. 58, in which both headers

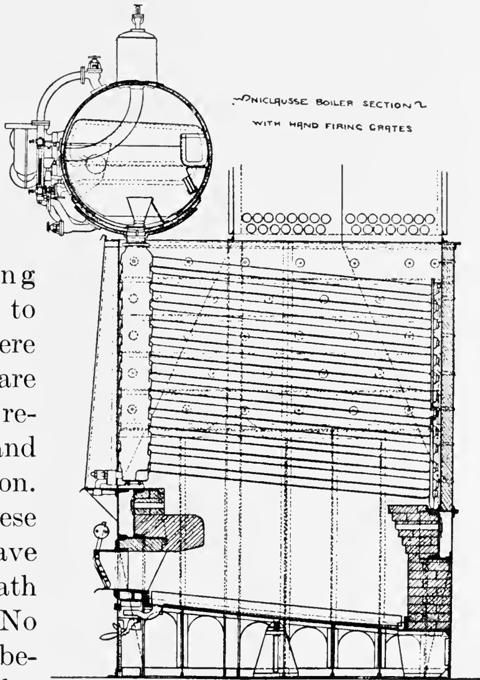

Fig. 58

are concentrated at the front of the steam drum, one as a box within the other. The far ends of the tubes receiving the heat are closed; each such tube, however, has inside it another tube, so that the steam when it forms runs uphill between the inner and outer tube to the header, together with some water that it drags along, and escapes upward through the header box, issuing through a funnel into the drum.

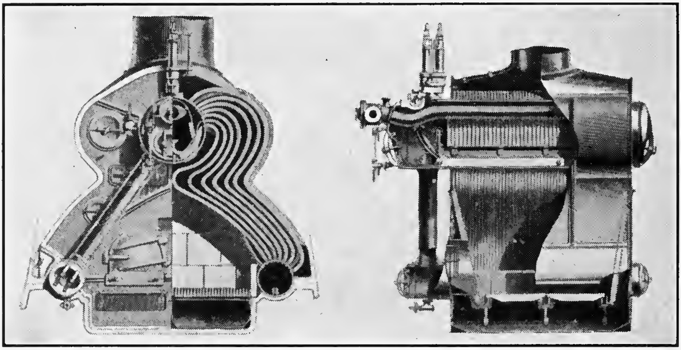

Fig. 59

The steam and water here disengage, and the water falls back and flows down through the header again, but on the other side of a partition, to the central tubes, then along these to their open ends, returning between inner and outer tubes to be again heated. Boilers of this water-tube class weigh about half as much per horse-power while in operation as those of the fire-tube type, and take up about half the space. One of the most concentrated forms of boiler is that shown in Fig. 59. The tubes are bent to peculiar curves, partly to secure distribution and partly to avoid leaks due to expansion, and enter the top drum above the water line, so that the circulation is positive. Any water that is carried up in them descends to the bottom drum through an outside large tube, shown at the side.

In addition to difference in form, total space occupied, floor space occupied, and weight per horse-power, boilers differ in cost per horse-power fully 100 per cent between the cheapest and the most expensive, the latter, of course, being the kind that has the most hand work on it, the greatest number of separate parts to be made and fitted together; the cheapest that which has least work for the amount of surface available for heating. There are likewise some differences in efficiency, which, in the case of boilers, is measured by the number of pounds of water that can be evaporated or turned into steam for each pound of coal burned, or the amount of heat that can be put into the form of steam for each unit of heat that the coal should liberate on combustion. Strange, indeed, it is that enormous variations in form produce little variations in best efficiency for each, so that all these forms may be said to have about the same efficiency if each is worked under its best conditions. These efficiencies range about 70 per cent, falling to 60 and rising to 80 per cent, with rare cases beyond these limits, which means that the steam which leaves the boiler contains on the average about 70 per cent of the heat liberated by the combustion of the coal in the fire, a performance which is reasonably good, but which seems to be due more to the management of the fire, based on an understanding of the conditions necessary for proper combustion of the fuel, than to the design of the boiler.

There is scarcely time available for studying all these conditions of combustion, recognition of which so largely controls boiler performance, but there are two important points in this connection that should be mentioned. In the first place, all the fuel supplied must be burned, and any furnace or fireman that does not permit it all to be burned is wasteful, not only of the coal, but also of time and of the investment required to build the boiler. On the other hand, whatever coal is burned requires air and a definite amount, different for different coals. Combustion is a chemical combination of coal and air, and in all chemical combinations the original substances combine with each other in a fixed weight ratio. Each pound of coal, then, will require a definite weight of air chemically to combine with it. If this amount of air is not supplied, the coal does not burn; if more is supplied, it may burn all right, but even greater harm may result than when the air is insufficient. The heat liberated by the fire will warm anything that comes in contact with it; if balls of iron were rolled into the fire and rolled out again, they would carry away heat that should have been making steam. If a stream of water was turned into the fire and it was not too large, it would not put the fire out, but it would rob the fire of heat in just the same way as did the balls of iron. And finally, if a lot of cold air is drawn into the fire, not needed to burn the coal, then as it escapes up the chimney it is likewise carrying off some of the heat that might have found its way into the water. This excess of air, as it is called, has just as much harmful effect on the efficiency of a boiler as a stream of water played on the fire would have; and it is the control of this excess of air that determines whether a boiler shall be efficient or not, more than any other single thing. The opening of furnace doors lets this air flow in unchecked, so that attention must be directed toward the reduction of this action, and it is to meet this that mechanical means for feeding coal continuously without opening doors have been designed and used. These will be referred to in the next lecture.

Passing over those accessories of the boiler plant provided merely for controlling its operation and its safety, economizing labor in handling coal and ashes, and conserving waste heat, together with the smoke-stacks, dampers, pumps for putting the water into the boiler, and devices to mechanically produce high draft to make coal burn fast, as well as the steam piping for conveying steam to the engine, as elements of secondary importance, however essential they may be to the actual running of the plant, there remains the engine and its auxiliaries to be examined.

As already explained, there are in use to-day piston and turbine engines, and the characteristic essential elements of each are very simple and the fundamental idea easily grasped. Why is it, then, admitting the essential simplicity of the necessary elements, that some engines can be built highly economical and others cannot? Why is it that some are complicated and others simple? Why is it that some may go either forwards or backwards at will, and others only turn one way; some rotate with most amazing steadiness of motion, regardless of how much work they are doing, while others fluctuate in speed badly; some are cheap, some very expensive; some capable of being built in large sizes and others only in small? The answers to these questions appear only when the elements of the engine which are non-essential to the production of power are studied in conjunction with conditions of operation. They are not due so much to reasons underlying the securing of power from heat as to the reasons underlying the way in which the power is to be generated.

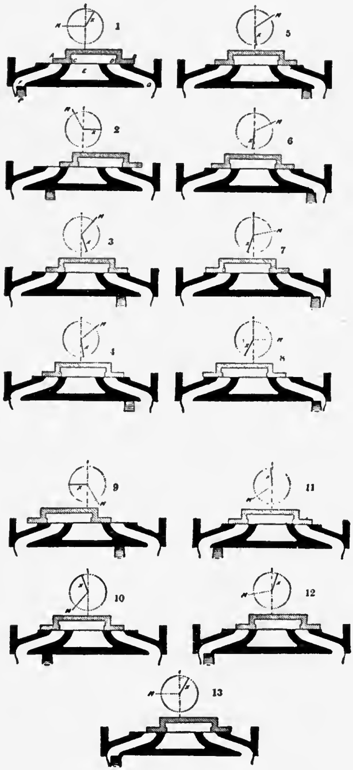

Fig. 60

In the case of piston engines, which will be first examined, most of the difference will be found in the system of valves and the control of their motion, each devised to meet some special condition of operation newly encountered or not previously recognized.

The simplest kind of valve for piston engines is that known as the slide-valve, which is a plate with a hollow on one side or a cylindrical rod having a smaller diameter along the middle, the latter form called a piston-valve. A simple slide-valve is shown in Fig. 60, in various positions in relation to the piston, shown only in part. The opening through which the steam may flow to and from the cylinder ends appears white, while the valve is lightly shaded and the metal of the cylinder is black. The valve moves from side to side in a box or valve chest, not shown, but to which the steam supply pipe is attached. In the first position the steam is entering the curved passage or port to the left-hand end of the cylinder, while from the other end of the cylinder the piston is pushing out steam through the other port, then through the hollow or the bottom side of the valve into the irregular-shaped space between the two ports which leads to the exhaust pipe. Movement of the piston rotates a shaft, not shown here, through rods and a crank, and as this shaft carries another small crank of special form, attached to rods, a reciprocating motion is imparted to the valve. This separate, peculiar crank is called an eccentric, and it and the connecting rods and valve constitute the valve gear which moves the valve from one position to another. The other positions of valve and piston shown in the diagrams illustrate how the flow of steam may be reversed from end to end, and that most important fact, how the steam supply may be shut off from the cylinder before the piston reaches the end of its stroke. Thus (2) shows the steam passage wide open to the left, (3) shows it closed with the piston only about three-quarters out, and all this time the right end is exhausting. At (4) the valve has moved back enough to close both ends, and they remain so in (5) and (6), though the valve is still swinging while the piston completes its stroke. The piston begins to return at (7), the valve has opened at the left to the exhaust, and is just about to admit fresh steam to the right. The remaining positions,

(8) to (13), illustrate the return to the original position. The relation of the slide-valve and its gear to the complete mechanism of an engine is shown in Fig. 61, which

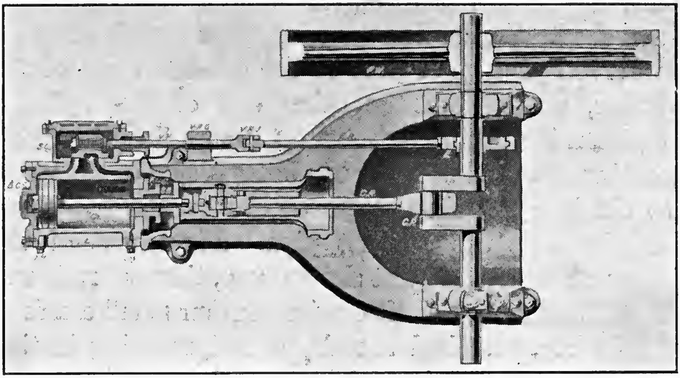

Fig. 61

is a cross-section through the important parts of a simple horizontal engine. Another form of slide-valve, made longer and designed to shorten the curved passages from

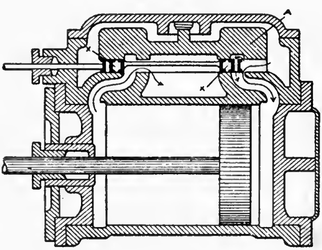

Fig. 62

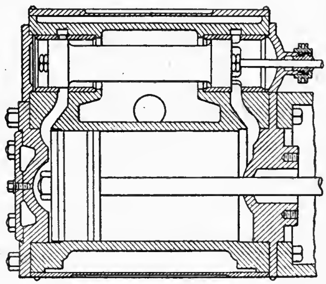

Fig. 63

the valve face to the cylinder, and so reduce the waste of steam incurred in filling this space without proportionate work, is shown in Fig. 62; while Fig. 63 is the piston-form modification of the slide-valve, which, being cylindrical, perfectly balances the steam pressure, acting on both ends instead of on the top of a flat plate, and has no tendency to make the valve bind on the seat and cause undue friction and wear. The variation of form which these valves take, as well as the greater variation in the mechanism by which their movement is controlled, is almost inconceivable to one unfamiliar with this work. The objects sought by the designers of this most important detail of the engine are economy and control, which are accomplished by changes of form of valve and its gear, and are always tending towards greater complication and cost, the simple and cheap kinds being retained because there is always a demand for inexpensive machines whether economical or not. To illustrate some of these modifications of valve form there is presented a series of sections from modern American engines. Those of Figs. 64, 65, 66, and 67 are quite similar to those already shown. In the next two (Figs. 68 and 69), however, there appears an im-

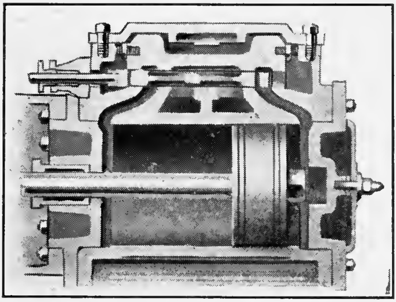

Fig. 64

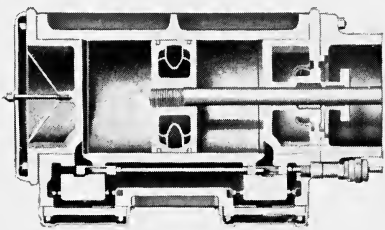

Fig. 65

portant modification; two sets of slides, constituting in effect four separate valves, are used, the pair on one side being for steam admission only, while that on the other side is for exhaust only, so that the adjustment of exhaust periods can be made independent of steam admission, a desirable thing quite impossible with a single valve. In large engines, which must have very wide ports, these slide-valves must be given considerable movement to get the steam passage open wide enough to admit the necessarily great quantity of steam in a short time, and to meet this difficulty a many-slotted or gridiron construction has been devised, as shown in Fig. 70, with twelve slots, so that full opening is secured with a movement only one-twelfth of what would be

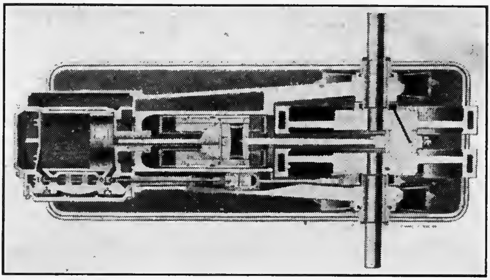

Fig. 66

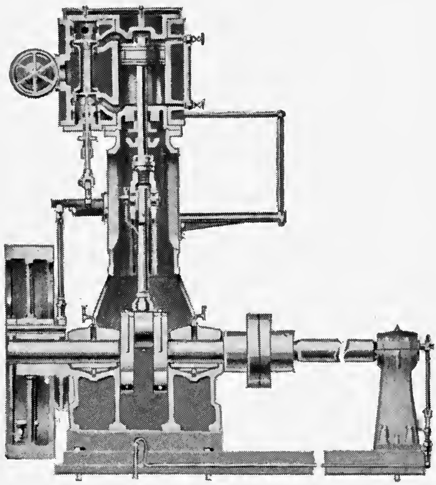

Fig. 67

necessary with a single passage of the same total area, thus reducing waste motion.

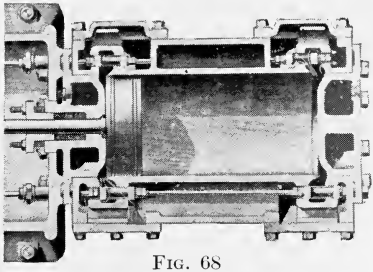

Fig. 68

The exterior view of two of these simple slide- and piston-valve engines is shown in Fig. 71, which is vertical, and Fig. 72, which is horizontal. Nearly all engines of this class are of small or moderate size and high speed.

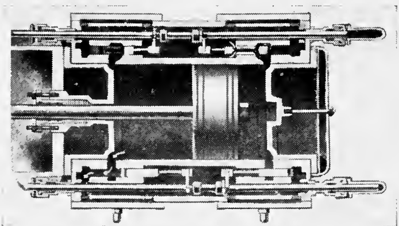

Fig. 69

For engines of larger size another type of valve and gear has been found better adapted, as it tends to keep tighter even when worn, and wears less; it also permits of a better control of the opening and closing periods, both for admission and exhaust steam. This is known as the Corliss valve, and like the slide-valve it is made in many forms and moved in a great variety of ways

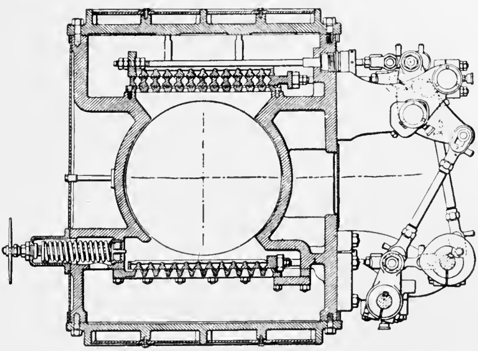

Fig. 70

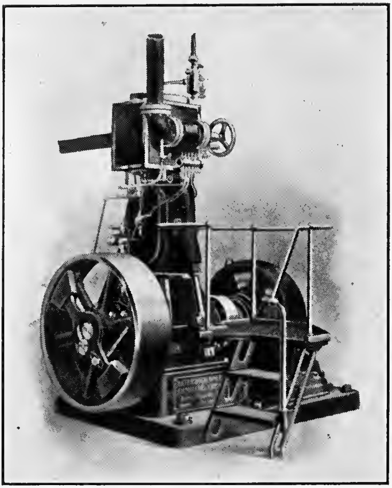

Fig. 71

by mechanism much more complicated, though ever so much more effective. The Corliss valve proper is a cylindrical block of metal with one side cut away, and it rotates in a round hole in the casting between the cylinder passage and steam supply, or between cylinder passage and exhaust, and there are always two valves for each end of the cylinder, or four in all. In Fig. 73 is shown a cylinder in cross-section, with the four Corliss valves in various positions and the relation of each to the piston, main crank, and valve crank or eccentric. Attached to the valve at one end and projecting through the casing is a small crank not shown, by which it is rotated through the pull of a rod derived from a system of rods, levers, hooks, and pins from the valve cranks or eccentrics on

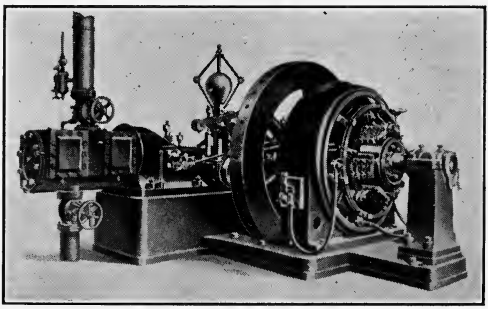

Fig. 72

the main shaft. One form of mechanism to move these four valves is shown in Fig. 74, partly in section and from both side and end of the cylinder, from which the complexity of parts is apparent, but all of which are present solely to give the proper movement to the valves and keep them under perfect control. Other forms of the valve proper and its location with reference to the cylinder are shown in Figs 75, 76, 77, and 78. The relation of the Corliss valve position to the rest of the engine mechanism is fairly well shown in Fig. 79, which represents a section of a large vertical engine. Two exterior views of simple Corliss valve engines, illustrating their varied form and the mechanism by which the valves are moved and controlled, are shown in Figs. 80 and 81, which also indicate the tendency toward the use of this class of engines in the larger sizes.

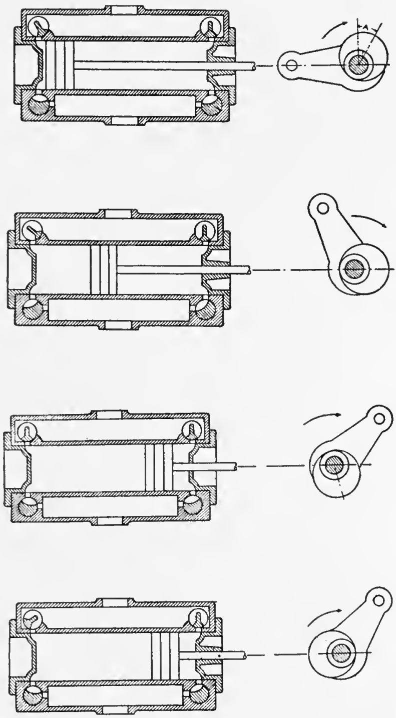

Fig. 73

All of these various types of valves, cylinder arrangements, and valve gears have been prompted, as has been said, by the desire for better control of the steam, which is basal to economical operation. In no case can steam be efficiently used if it is allowed to follow

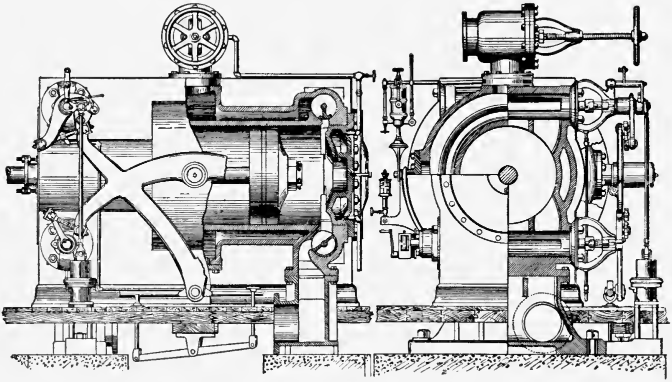

Fig. 74

the piston at full pressure for the whole piston stroke. This principle was discovered by Watt, but not generally understood in its fullest significance for many years.

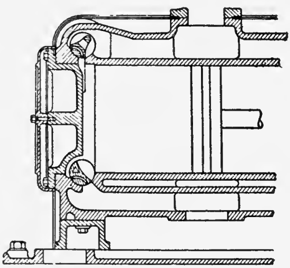

Fig. 75

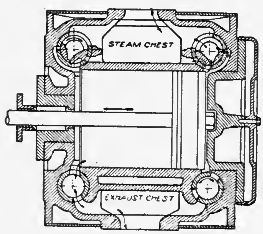

Fig. 76

The force of this as a controlling idea in steam economy did not really appear until innumerable tests of steam consumption had been made, and the attempts made to explain the differences found finally resulted in the creation of what has been explained as thermodynamics. These tests and the thermodynamics which grew out of them show that not only must the differences between the steam pressure and the final pressure be as great as possible, thus calling for the use of high-pressure boilers and good condensers for the most economical use of steam, but also, and perhaps more important, that the full use cannot be made of this range of pressure until the admission of the steam has been controlled in a certain definite way. For every range of pressure from the initial to final there is a certain range of volume through which the steam must pass to give the most results in work per pound of steam. The reasons for this need not be gone into here, as this would involve somewhat complicated mathematics, but a cubic inch of high-pressure steam may be imagined as similar in character to a compressed spring. When compressed, this spring exerts a certain tension in the beginning which runs down to something less at the end as the spring

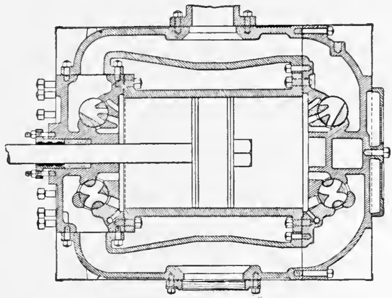

Fig. 77

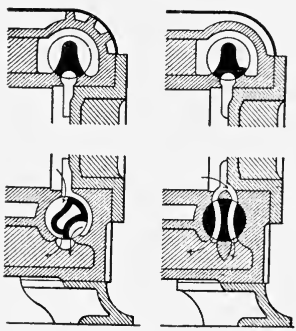

Fig. 78

is released, and at the same time is growing in size. It is evident that a long spring much compressed can do more work as it expands than a short spring lightly compressed. The extension of the spring is somewhat analogous to the stretch of expansion of the steam. The most work will be obtained with the most expansion for a given spring or for a given amount and kind of steam. Accordingly only a little steam is admitted to a cylinder. This little bit represents the spring compressed. The valve is then closed and as the piston moves out the steam expands or stretches, pushing the piston throughout the stroke, as would the spring as it was released. If at the end of the stroke the spring is entirely released, it has done all the work it can do. Similarly, with regard to the steam; if at the end of the stroke its pressure has fallen to that of the condenser or atmosphere, it has done all the work it can do under those conditions, and when the steam has done all the work it can do, then the most work has been obtained per pound of steam, or the greatest economy of steam results. These conditions impose on the valve and valve gear a structural condition, — that the steam valve shall open a little bit and then quickly close. With the slide-valve first examined it is impossible to secure the admission and cut off of the

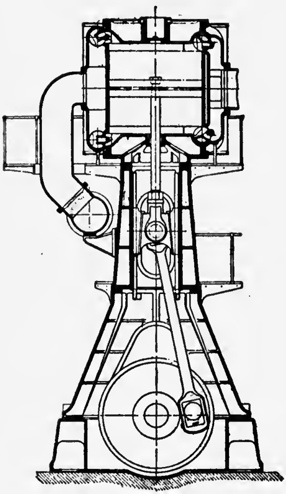

Fig. 79

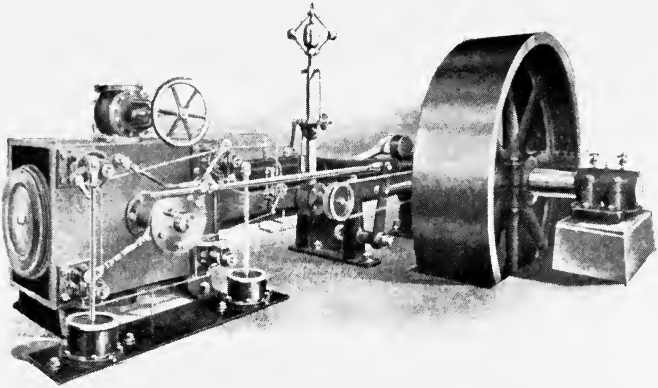

FIG. 80

steam supply at a proper time, independent of the openings and closing of the exhaust, because it is a one-piece affair. The use of two separate slide-valves, one for exhaust and one for admission, helps matters consider-

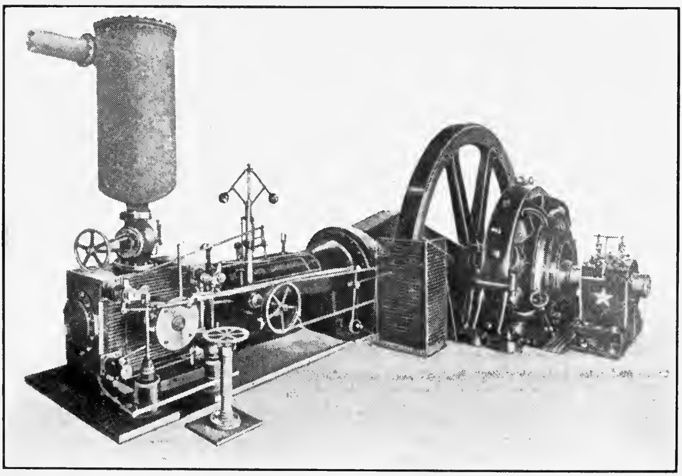

 FIG. 81

ably; but the Corliss valve structure permits of the greatest possible controlled independence. This discussion shows that the first step in the economic use of steam is a matter of mechanism design to permit of the movement of the valves in a suitable way, the suitability of the way being dictated by the thermodynamic laws governing the relations of heat and work.

Were there more time available, it would be interesting to trace the influence of the character of service on the changes of form of engines and their parts, but this would require a detailed history of design, which would show that greater and greater diversity is entering into the construction of engines to secure the best possible adaptation to requirements, contrary to the practice of the early days when there was only one steam-engine and that put to work at all sorts of things.

As already pointed out, the steam-turbine type of engine was conceived nearly two centuries before it came into use: and the reason is to be found, first, in the lack of demand; and second, after the demand that gave Watt his chance had been created, then and for nearly one hundred and fifty years, in the failure to understand how to make it as economical as the piston engine. Steam can do the same work expanding between the boiler pressure and that of the exhaust, whether it happens to be in nozzles or behind pistons, even though in the former case the work done is not yet in available form, but exists in the form of a high-speed jet of steam. Returning, for illustration, to the compressed spring analogy, it is true that if the spring is compressed between the fingers and a table, it will jump up when released; the energy of the compressed spring, measured by the work it can do as it is released, is expended in giving itself a velocity. This is precisely what happens in the steam nozzle. The difficulty in respect to economy in the turbine is, however, different from that in the piston engine, where the problem is to admit a small amount of high-pressure steam and let it completely expand without interference. There is no difficulty in getting complete expansion of steam in nozzles; the really great difficulty lies in the relations of the wheel and vanes to the steam jet. If the vanes move too fast, the steam from the nozzle may never catch up, and so cannot exert any push or do any work. Similarly, if the vanes move too slowly, the steam jet will bounce off with nearly as much velocity as it had before and, therefore, carry away nearly all its original energy. It appears, then, that the vanes must have a velocity neither too low nor too high, but definitely related to the jet velocity in order to secure best economy. It does not appear, however, what the jet velocity will be for any given steam pressure, or what the relation of the two velocities should be. This determination can be made mathematically to-day, and it is only within a score or so of years that it could be made. Without this knowledge, properly applied, the steam-turbine may be enormously wasteful; for example, one machine that was built by guess consumed over a thousand pounds of steam per hour for one horse-power, about one hundred times as much as a properly proportioned machine would use under the same conditions. It is a fact that for ordinary pressure conditions the steam jet will have a velocity running into thousands of feet per second, and approximately equal to that of a rifle bullet, so that to get suitable velocity relations for good steam economy the vanes must either rotate too fast for safety, or their speed must be held down to some safe low value that will necessitate waste of energy, or some new means of treatment must be devised.

This last step, the devising of new means of treating jets and vanes in turbines to permit of safe and otherwise desirably low speeds, with properly good economy in the use of steam, will be taken up later, together with a new treatment of the piston engine similar in kind and effect to give higher economies than are possible with the simple piston machines already discussed.

IV

PRINCIPLES OF EFFICIENCY IN STEAM-POWER SYSTEMS

It has required far more effort, and effort of a far higher order, to make the steam system of power generation as economical as it is to-day, than was required to produce the first successful rotative engine. Without the study of efficiency and reduction of heat waste it is safe to say that but little progress would have been made in comparison with that which has been made. Even up to the year 1870, ninety years after Watt's successful engine, the use of the steam-power system in this country for stationary work was less extensive than the use of the water-power, and the reason is to be found chiefly in the relative costs of power by the two systems up to that time. Although improvements in water-power machinery since then have decreased its cost somewhat and have made it possible to develop more difficult waterfalls, and through electric transmission to increase the areas over which water-power might be used, yet these advances are as nothing compared with the advances in the steam-power system. All advances in the steam-power system have come from improved shop methods and from analysis of losses through the methods of thermodynamics, a science which itself grew out of the earlier engines, which furnished means for getting test data which thoughtful men have compared, and in the comparison discovered the general laws.

Even with the best boilers and engines of the so-called simple type, such as have been shown and described, the economy is poor. The boilers give to the steam on an average 70 per cent of the heat of the fuel or, what is roughly equivalent, produce 10 pounds of steam per pound of good coal, or less per pound of poor coal. The engines, even of the better sort, exhausting to the atmosphere use 30 or 40 pounds of steam per hour per horse-power, so that such boilers and engines together would require 3 to 4 pounds of coal per hour per horse-power, which amount will rise in the small and less well-constructed units to as high as 6 and 8 pounds. A coal consumption of 1 pound per hour for each horse-power corresponds to a plant efficiency of approximately 17 per cent; 3 pounds to about 5.6 per cent; 4 pounds to about 4.2 per cent; 8 pounds to 2.1 per cent,—so that these non-condensing steam plants with simple engines burning from 3 to 8 pounds of coal per hour per horse-power, which is the range they cover, are capable of converting into useful work only from 5 to 2 per cent of the heat the coal contains. Improvements in the apparatus and methods of working have raised this value to about 15 per cent in the best modern plants, which seem extremely complicated compared with the simple non-condensing ones. Great as is this improvement, the efficiency still seems small, but it is difficult to realize the cost of time, material, money, and brains that have been expended in making even this advance.

Such improvements as have been made are of two general classes: first, those belonging strictly to the engine to increase the work obtainable per pound of steam; and second, those relating to the efficiency of steam generation to increase the weight of steam made per pound of coal. Most of those which have been applied to the generation of steam have been directed toward the reduction of direct heat losses, and the return to the boiler water of some of the waste heat. For example, while the hot gases leaving the boiler must be hot when they reach the chimney to produce a proper draft, they may carry more heat than is necessary for the draft, so that some heat is wasted. Also the exhaust steam from the engine carries much heat away to be dissipated in the atmosphere, or given to condensing water. If, therefore, the cold water on the way to the boiler be brought in contact with the exhaust steam or flue gases, it will become warm, and therefore require less of the direct coal heat to make it boil. As the heat for boiling the water is more and more derived from waste sources and less from the coal directly, the efficiency of steam generation will rise and more steam will be made per pound of coal. Apparatus designed to save waste flue-gas heat is called an economizer, and consists of a bank of tubes through which the water passes on its way to the boiler, generally set behind a row of boilers and a little above. This is shown in Fig. 82, which represents a set of economizers being erected behind a row of horizontal inclined water-tube boilers in the plant of the Public Service Corporation, Newark, New Jersey. To secure the advantage of heating the boiler feed-water by exhaust steam, an apparatus called a feed-water heater is used, and of this there are two general classes. In that shown in Fig. 83 the water passes through a bank

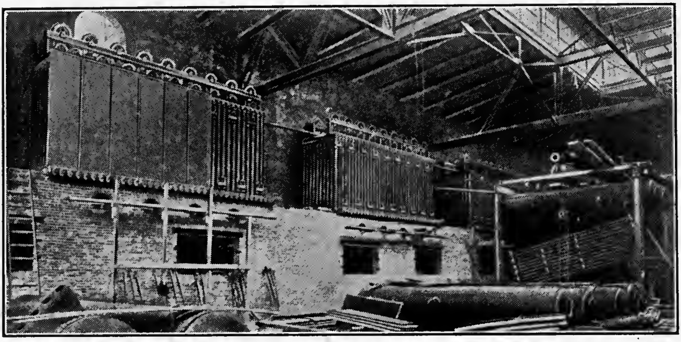

Fig. 82

of small tubes set in a cast-iron casing through which the exhaust steam passes. As there is no physical contact between the steam and the water, the water remains unchanged except as its temperature rises.

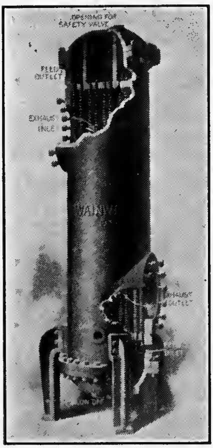

Fig. 83

This is not the case with feed-water heaters of the other class, in which the water and steam mingle, one of which is shown in Fig. 84. Here the cast-iron casing through which the exhaust steam flows is fitted with a number of cast-iron trays over which the water falls and becomes heated. Steam that condenses, together with any oil that it may have carried over from the engine, falls with the feed-water to the bottom, where filtering material is added to remove the oil. These feed-water heaters and economizers are only two of many means of returning heat waste to the boiler that are now important subjects of study in plant economy.

As has already been explained, improperly controlled air supply to the furnace means heat waste of the most direct sort, either by failing to burn all the fuel, when the air is insufficient, or through using more air than is needed, carrying away to the chimney too much heat in the form of hot gases. Much work is being done to reduce these losses, and in this part of the problem perhaps the most important piece of apparatus developed is the mechanical stoker and its furnace.

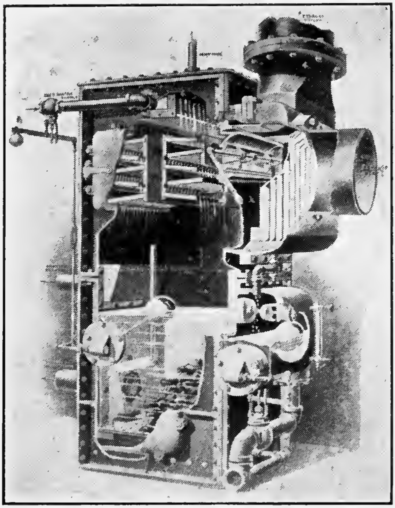

Fig. 84

These stokers are intended to maintain proper furnace condition continuously, by feeding coal mechanically to furnaces fitted with properly controlled air openings. The use of these stokers is likewise associated with some saving in labor in handling the coal, which is mechanically elevated from boats or cars to bins over the boiler room, from which it runs down to each boiler through pipes. The elaborate nature of some of this coal-handling equipment is well shown in Fig. 85, illustrating the river side of the New York Edison

Power Station. Each stoker has a hopper supplied with coal from the overhead bins by pipes, as shown

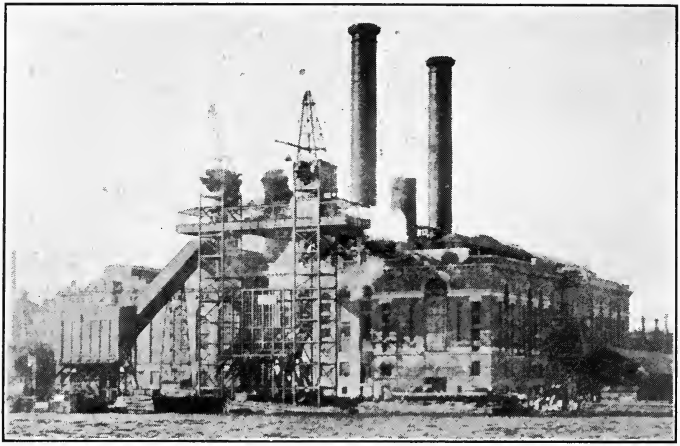

FIG. 85

in Fig. 86, which illustrates the fronts of a row of boilers mechanically fired by that form of stoker known as the chain grate. This chain grate is like a wide belt of cast-iron links, as shown in Fig. 87, receiving the coal at one end from the hopper and continuously carrying it back into the fire at a proper speed, so that when the coal reaches the end there is nothing but ash to drop

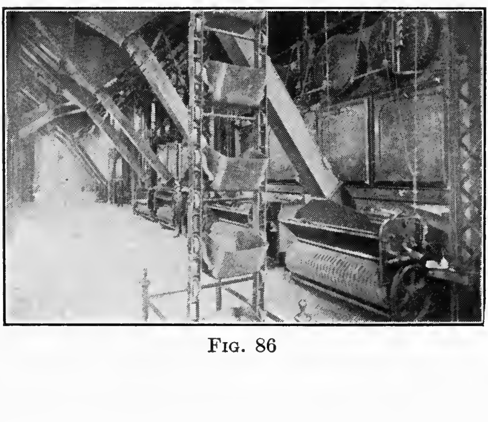

FIG. 86

off. In the picture the stoker is shown pulled out for inspection or repairs. Another form of stoker, consisting of a set of moving bars on an incline, is shown in Fig. 88 in cross-section, in which the agitation of the coal is possible, a thing very desirable for some sticky kinds of coal. These illustrations tell only the smallest fractions of the story of attempts to reduce heat waste and get more steam per pound of coal, and will serve to demonstrate the nature and direction of the efforts. Their effect has been not so much the improvement of boiler efficiency, comparing the best stoker performance with that of the best hand-fired furnace, as to enable a better average condition to be maintained than is possible with intermittent hand-firing, with all the variations of fire condition and

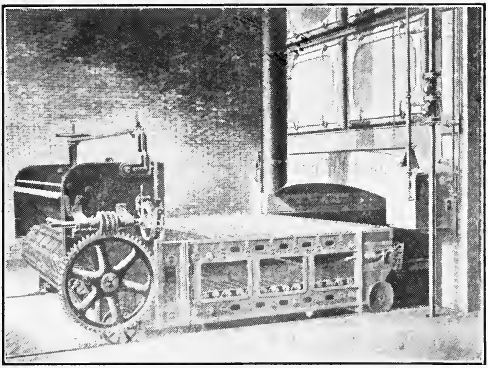

Fig. 87

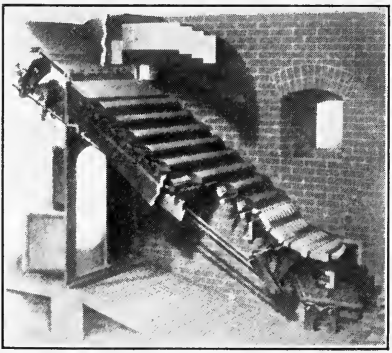

Fig. 88

air supply entirely subject to the judgment of the fireman, for the stoker maintains steady conditions and reduces the evil that a poor fireman may do.

It is in the engines and their auxiliaries that the greatest advances have been made, but improvements directed toward the fullest utilization of the work capabilities of steam can be understood only when some of the important quantities are known. It is these quantities that show plainly the difficulties to be encountered in designing apparatus to carry out the processes to the fullest extent. It has already been explained that steam will do all the work it is capable of doing only when permitted to expand or stretch as much as it is capable of stretching, in just the same way as a compressed spring may stretch or expand to do work. It is important now to consider how much steam, under the ordinary conditions of initial and final pressure employed, may stretch or expand. A boiler pressure of 150 pounds per square inch is not considered high to-day, as pressures going up to 250 pounds are in common use; but even with the moderate pressure of 150 pounds to start with, one pound of steam would occupy a volume of $2\frac{3}{4}$ cubic feet. That is to say, one pound of water when turned into steam at 150 pounds pressure would occupy a volume of $2\frac{3}{4}$ cubic feet. If this steam, which may be likened to a compressed spring, be allowed to stretch until its pressure has come down to that of the atmosphere, then it will occupy a volume of 23 cubic feet, or it will have expanded 8.1 times, or, as it is often said, it will have suffered 8.1 expansions. If, however, it be allowed to continue to stretch by the enlargement of the chamber in which it is working, until its pressure has fallen below atmosphere to about 96 per cent of a perfect vacuum at sea-level, such as is obtainable in our best modern condensers, then it would occupy a volume of 401 cubic feet or would have expanded 150 times its original volume. This means that one cubic foot of steam at the high initial pressure of 150 pounds per square inch becomes 150 cubic feet when its pressure has been brought down to about 96 per cent of a perfect vacuum. The more a spring is allowed to stretch, the longer will it continue to push against whatever is restraining it and so the more work it will do. Similarly, the more the steam is allowed to stretch or expand, the more work it can do. It appears, therefore, that steam expanding from this high pressure to the vacuum can do more work than if it expanded only to the atmosphere, and it is interesting to note just how much more. The laws of thermodynamics indicate that when expanding from the high pressure to atmosphere, steam can only do about 54 per cent of the work it could have done had it expanded to the vacuum. This is equivalent to saying that the work of expansion from the high pressure to the vacuum nearly doubles the work it could do if the expansion stopped at the atmospheric pressure. As a consequence, the more complete expansion nearly doubles the efficiency of its use and so reduces the waste in its use to nearly one-half. This being the fact, it appears that to make the best use of steam from 150 pounds to 96 per cent vacuum in a piston engine, the piston should start at the beginning of its stroke (assuming it to be working with one pound of steam) with $2\frac{3}{4}$ cubic feet of steam in one end when the supply is cut off, and the piston movement should continue until the space within the cylinder occupied by the steam has become 401 cubic feet, or 150 times as much as it was in the beginning. If this is done, then as much work will be obtained as the steam is capable of doing, provided none of it is lost by leakage or is condensed by cooling during the process. This seems a simple requirement which, if carried out, would yield a high efficiency piston engine, yet as a matter of fact it is absolutely impossible to do it at all in a single cylinder.

Attention has already been called to the existence of a series of spaces in the end of a cylinder. There is a steam-passage space between the valve and the cylinder, and another space between the end of the piston and the cylinder head to avoid the possibility of the piston striking the head. The sum of these spaces together is called the clearance volume. About the smallest clearance volume, that even the best arranged valves will permit, may be set at 2 per cent of the cylinder volume, and even this is almost dangerously small. To carry out such expansion as has been discussed, the volume of steam at the beginning of the expansion should be only about .7 of 1 per cent of the volume at the end of expansion, or less than the dead clearance space itself. If steam were admitted to the cylinder for only $\frac{1}{20}$ of the stroke of the piston and then cut off, it could expand only 14 times. If steam were admitted only to fill up the waste space and did not follow the piston in its movement at all, then it might expand only 51 times instead of the 150 which is necessary to get all the work it is capable of giving. These figures show the absolute impossibility of carrying out this expansion process in a single cylinder and why single-cylinder or simple engines are necessarily wasteful.

When, however, the work is done in two cylinders in succession, or even three or four, the conditions are changed. This process of successively working the steam in several cylinders in series, called multiple expansion, will permit of more expansion in such cylinders as we can construct than is possible in a single cylinder. Suppose, for example, the first of the series to be just large enough to hold the pound of steam when full, then if the largest cylinder have a volume 150 times this, the expansion would be possible. This would call for a low-pressure cylinder diameter about fifteen times that of the first or high-pressure cylinder. These so-called multiple expansion engines are, therefore, capable, for this, as well as for some other reasons, of making better use of the steam than the simple engine.

When several cylinders use the steam in succession, permitting the pressure to fall in steps and producing the work of the steam in stages, the cost of the engine increases. A two-cylinder or compound engine will cost about 50 per cent more than a simple single-cylinder engine, while the third and fourth cylinders for triple and quadruple expansion add still more initial expense, which is the price to be paid for increased steam and coal economy. Evidently a limit will be reached somewhere, beyond which successive expansion cylinders will cost more than the fuel saving will warrant, and this limit is found with the two-stage or compound engine in stationary, and the three-stage or triple engine in marine practice.

When the two cylinders of a compound or two-stage expansion engine are in line with each other and both pistons are on the same piston rod, the engine is called a tandem compound. Fig. 89 shows a cross-section of a tandem compound arrangement with two slide-valves, and Fig. 90 a similar arrangement with a piston-valve on the high-pressure cylinder and a slide-valve on the low-pressure. The exhaust from the high pressure is led to the steam chest of the low. The external appearance of a tandem compound engine with slide-valve is shown in Fig. 91, and another tandem compound of larger size with Corliss valve is shown in Fig. 92. It is perhaps more common to arrange the cylinders of compound engines side by side, with separate rods and cranks, and this arrangement is called a cross-compound. A vertical cross-compound engine, having a piston-valve on its

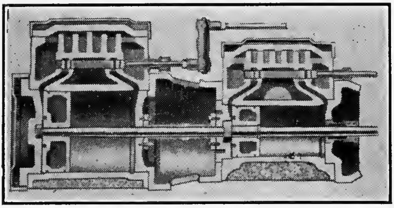

Fig. 89

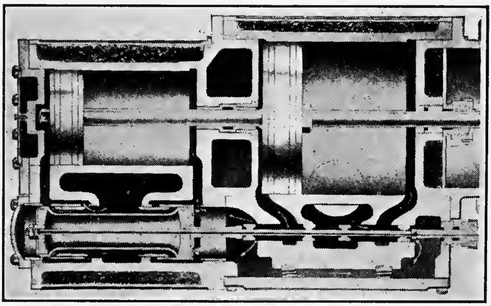

Fig. 90

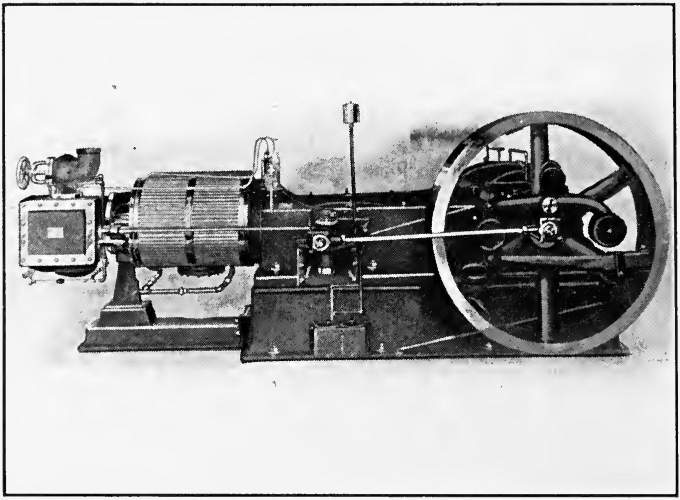

Fig. 91

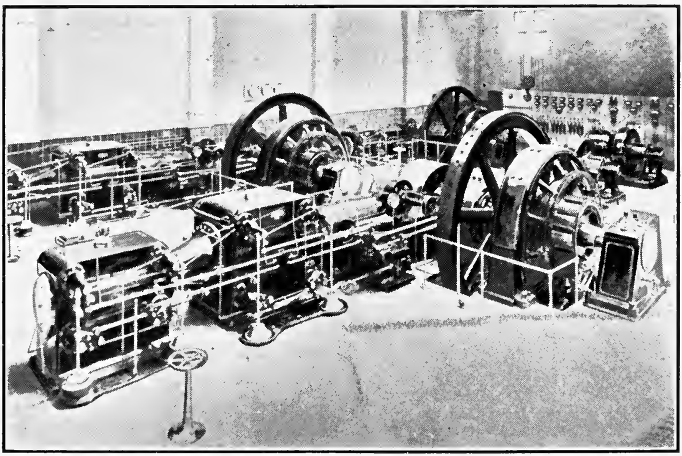

Fig. 92

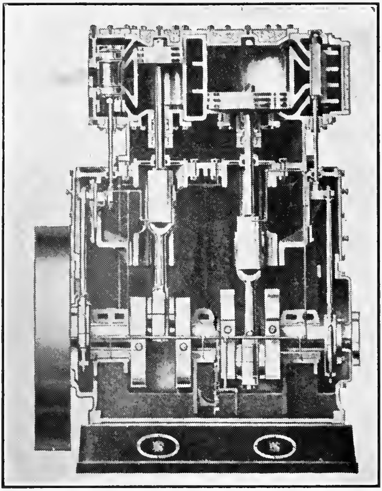

Fig. 93

high-pressure cylinder and on the low-pressure a slide valve, is shown in Fig. 93. Another larger horizontal one with slide valves is shown in Fig. 94, and a still larger cross-compound slide-valve engine with gridiron valve is shown in Fig. 95. Two larger Corliss compounds, one vertical and the other horizontal, are shown in Figs. 96, 97. One cylinder placed vertical and the other horizontal gives what is called the angle-compound construction, such as is used in many larger railway and central station power houses in pairs, as shown in Fig. 98.

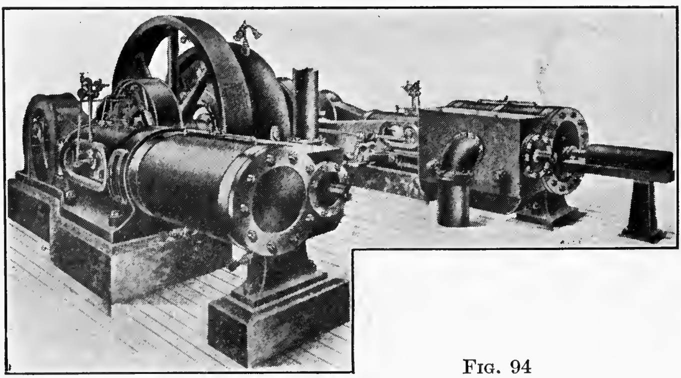

Fig. 94

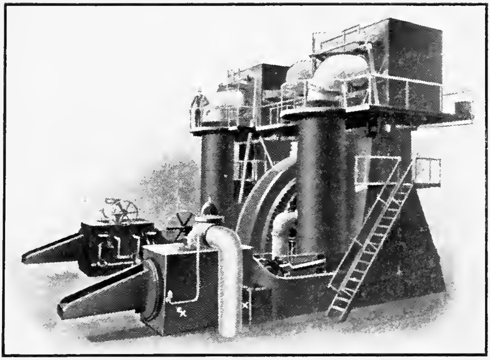

Fig. 95

No piston engines are made with cylinders enough in number and size to be capable of utilizing the full expansion of the steam, because the increased cost of the larger cylinders more than overbalances the saving of fuel. It has remained for the steam-turbine to supply a cheaper means of taking full advantage of high initial and low final pressures than indefinite multiplication of large cylinders.

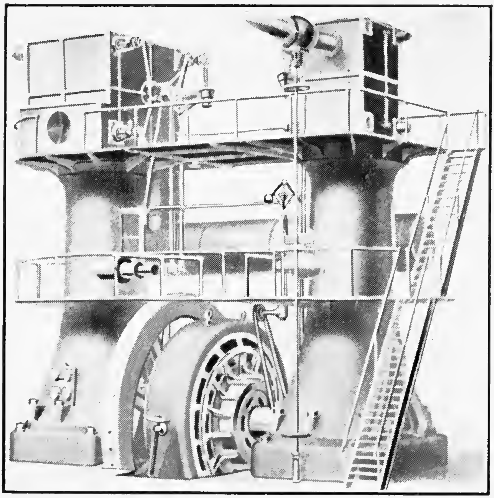

Fig. 96

The steam-turbine problem, however, is not so simple as it seems, for, as already pointed out, it is necessary but difficult to arrange wheels and vanes capable of moving fast enough to make the best use of the high velocity steam jet. It is easy, however, to get complete steam expansion in the nozzle forming the jet and to

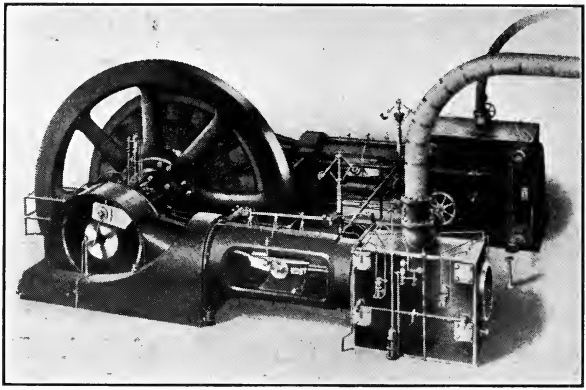

Fig. 97

form jets having such a velocity as will represent all the work the steam is capable of doing. To get a clear idea

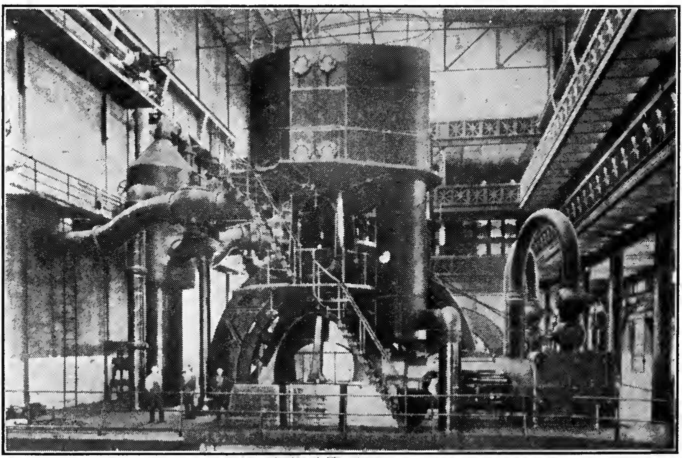

Fig. 98

of the difficulty to be met it is necessary to know the velocities of steam jets, which the thermodynamic laws supply means to calculate. For example, steam expanding from 150 pounds per square inch boiler pressure to atmosphere would acquire a velocity of 3000 feet per second or 2000 miles per hour, about forty times as fast as the average express train; and if it expanded to a vacuum 96 per cent perfect, its velocity would be 4100 feet per second or nearly 3000 miles per hour. Perfectly executed expansion of the first sort would give to the jet energy of motion equal to 15 per cent of the heat put into the steam, and perfectly executed expansion from boiler pressure to the vacuum would make jets having energy of motion equal to about 28 per cent of the heat content of the live steam. No higher efficiencies than these would be possible, no matter how perfect the mechanism. Just in proportion as the velocities of wheels and these fast steam jets are correctly adjusted, and leakage and friction losses reduced, so may these efficiencies be produced, otherwise not. Single vane wheels should run at speeds a little more or less than half the jet velocity, so that for the complete expansion to a vacuum the speed of the wheel should be such as to give about 2000 feet per second vane velocity, at which value the wheel would burst. To prevent blowing up the wheels, governors are used to keep the speed down to a safe value, at which speed only a part of the energy of the steam jet can be taken up by the wheel, so that all such single-wheel turbines are necessarily wasteful. Small turbines are, however, made, and being cheap find some useful fields. One of these machines carries little cups on the circumference of the wheel and a number of nozzles are spaced around, as shown in Fig. 99; while another has curved slits cut in its edge to form the vanes, as shown in Fig. 100. In the latter case the steam passes through the wheel and this is the more common form. Another way of making vanes on the edge of wheels for the steam to pass through from side to side is shown in Fig. 101, in which they are dovetailed into a groove. The external appearance of a single-wheel turbine, constructed as shown in Fig. 100, is illustrated in Fig. 102, as built to drive two electric generators by two gear-wheels, which reduce the speed to a safe value for the electric generator. The two large central boxes contain these gears, while the narrow chamber at the right end is the wheel chamber, the nozzle valves appearing plainly on the circumference. The problem of correct adjustment of wheel speed to steam jet speed necessary for high economy, yet allowing the wheels to rotate slow enough to avoid bursting, or slow enough to be adapted to drive standard machinery, most of which does not rotate very fast, has been solved only within the last ten years. The method applied to this solution is similar to, but more perfectly carried out than, that used in the piston

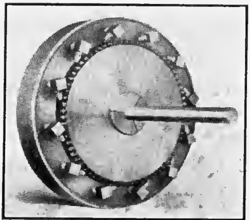

Fig. 99

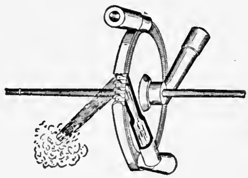

Fig. 100

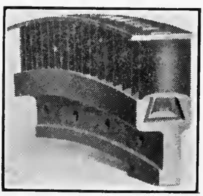

Fig. 101

engines, that of division of the duty into stages. Economical low-speed steam turbines must be multi-stage machines, and the staging may be carried out in two characteristic ways. In the first way, called pressure staging, the full velocity due to the final and initial pressures is never realized, but only a part, then a little more, and so on. Thus, if a series of chambers be arranged in a row, as in Fig. 103, with a steam supply pipe leading to the first, and nozzles leading from chamber to chamber of appropriate size to reduce the pressure in the successive chambers by say 50 pounds per nozzle, the last chamber being connected to a condenser, and in addition a vane wheel be placed in each chamber, then, instead of one jet with a velocity equal to the whole drop in pressure, there are five jets in series, each with a velocity due to 50 pounds pressure, a very much smaller amount. When many nozzles are placed between stages, the partition begins to resemble the vanes; differences, however, exist in shape and area of opening. A view of a casing for a multistage turbine in which the nozzles look like the vanes them-

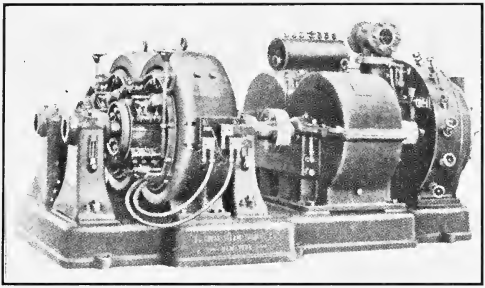

Fig. 102

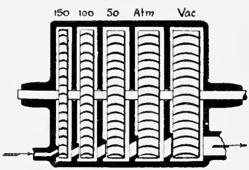

Fig. 103

selves is shown in Fig. 104. The other way of meeting the velocity difficulty, and the second method of solution, is to use the principle of successive impulse, or a series of bounces, the steam being given its full velocity in one nozzle, all the wheels rotating in a chamber of the same low pressure, maintained by the condenser,

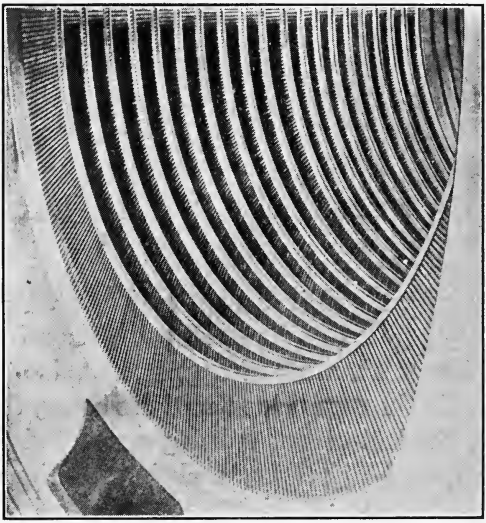

Fig. 104

and the steam jet striking one wheel after another, being guided between by openings in fixed partitions. Each time the steam strikes a vane it gives it a push and loses some velocity, so that finally it emerges with no velocity, having given up its energy to the wheels in many velocity stages, the process being termed velocity staging. Modern turbines are built for both methods of staging, using the jet both by impulse and reaction, and with all sorts of structural details, but in every machine there are great numbers of fixed guides and moving vanes differing more in curvature and areas of passages than in general external form. In Fig. 105 is shown a cross-section of a four-stage turbine through the nozzle and guides. The complete machine, de-

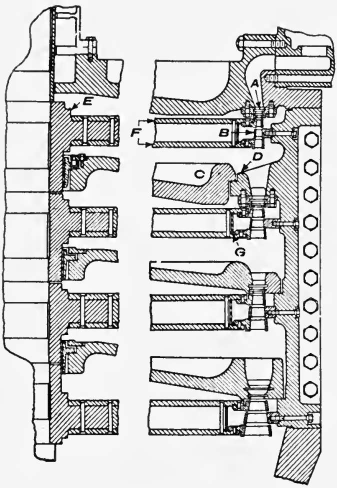

Fig. 105

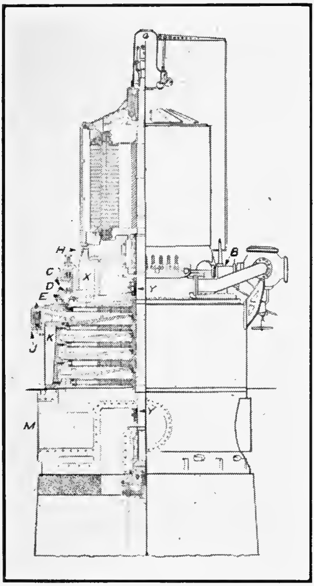

Fig. 106

signed for about 15,000 h. p., is illustrated partly in section in Fig. 106, which shows the electric generator above mentioned, rotating on the same vertical shaft as the wheels. The interior of the power station of the Commonwealth Electric Co., containing machines of this type, is shown in Fig. 107. This station is designed for about 150,000 h. p. One of the most interesting

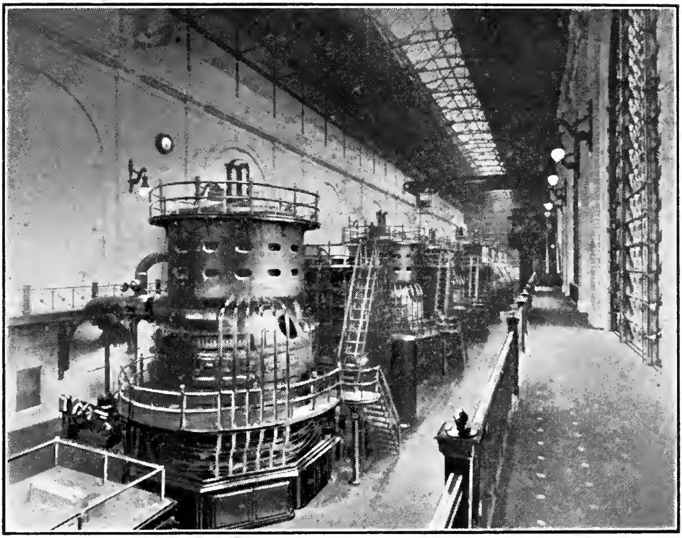

Fig. 107

installations recently made is that for the new battleship, *North Dakota*, built by the Fore River Co., and which is equipped with about 30,000 h. p., shown in Fig. 108, and which on trial made a record for economy.

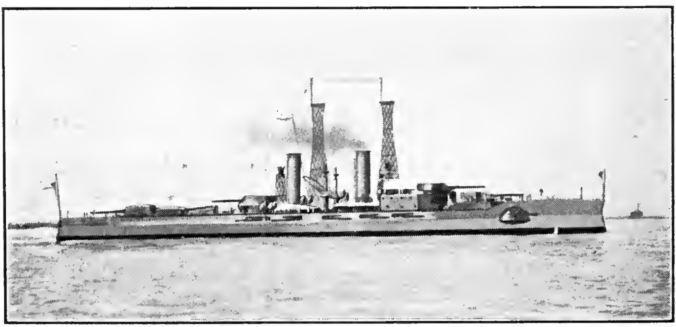

Fig. 108

This turbine complete, as it appeared in the shop, is shown in Fig. 109, and the upper half of the casing,

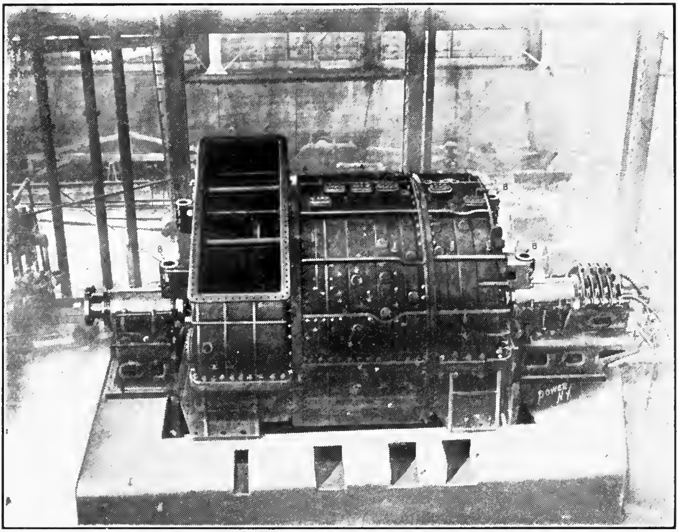

Fig. 109

in which the guide vanes are clearly seen, in Fig. 110, while the wheels with successive rows of vanes fitting between the rows of guides are shown in Fig. 111.

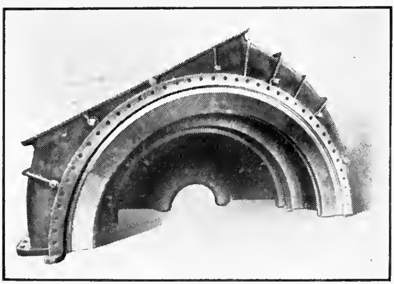

Fig. 110

These steam-turbines can be built at about one-half the cost of compound piston engines or less, so that they offer a cheaper means of developing into useful work the work capabilities of expanding steam. This fact has led to their adoption in place of additional cylinders to compound engines, the exhaust from the compound running the turbine instead of passing to a third or fourth cylinder of triple and quadruple engines. One such installation, just completed in the New York Subway power house (Fig. 112), was able to develop as much power in the turbine as did the large compound engine, the waste steam from which supplied the turbine, and

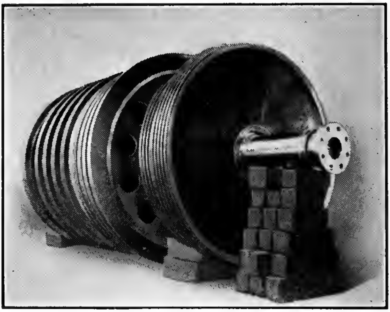

Fig. 111

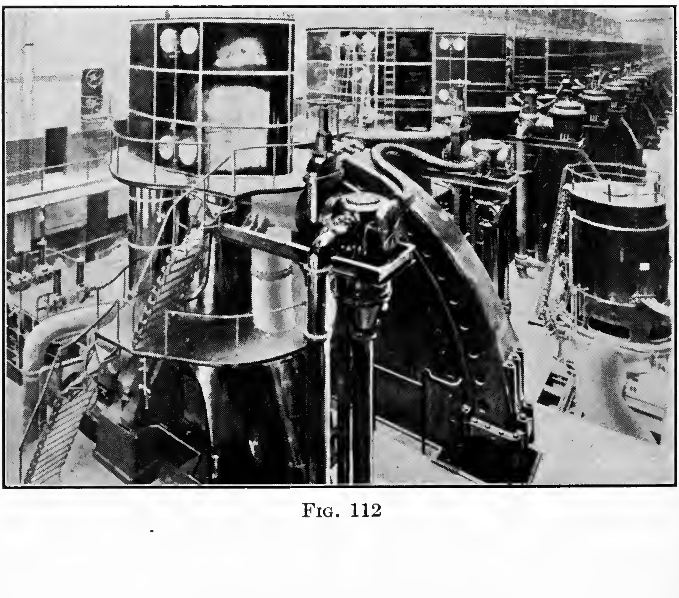

Fig. 112

so brought down the coal consumption to a trifle over one pound per hour for each horse-power, the most economical record for a steam-power station in daily service.

The reduction of the pressure in the exhaust passage of the engine, such as happens when condensers are used, and which may be made lower and lower as the condensing equipment is better and better, increases primarily the work that the expanding steam may do, and that may be realized if the engine is of suitable type or construction. Condensing equipment may, therefore, be considered as apparatus designed primarily for economy in the use of steam by engines, and there have been great advances in recent years in the attainment and maintenance of a good vacuum for just this purpose; but space will not permit of a consideration of condensing equipment, however desirable that might be, beyond a few pictures to illustrate the nature of modern condensers. Passing the exhaust steam through a cast-iron casing filled with small tubes through which water is pumped, is the surface condensing method. One very large surface condenser, such as might be used with steam turbines,

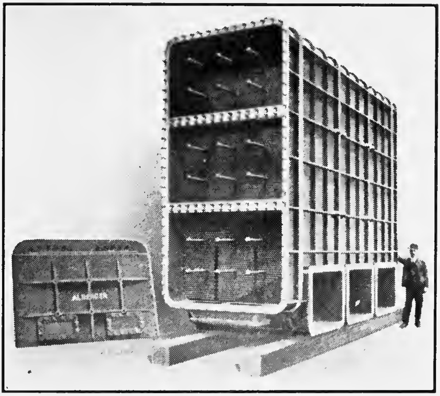

Fig. 113

is shown in Fig. 113, with one end plate removed to show the tubes starting from the inner partition plate.

Another condenser of smaller size is shown in Fig. 114. Surface condensers of this class require two pumps at least to operate them, one to send the circulating water through the tubes, which water is often taken from a near-by river and need not be especially clear or pure, a fact that prompts the location of plants on water fronts, and the other to pump out from the vacuum chamber all the water of condensation. This latter type of pump is called an air-pump, vacuum-pump, or hot-well pump. One common type of vacuum-pump used for this purpose is shown in Fig. 115. It has a conical piston which is moved up and down in its cylinder by a vertical steam-engine above. The cylinder has slits in the side, and the casing surrounding the cylinder into which the water from the cylinder runs has a curved guide. The

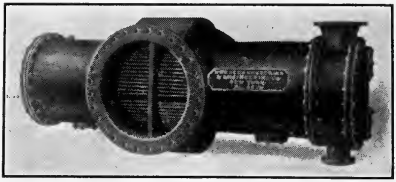

Fig. 114

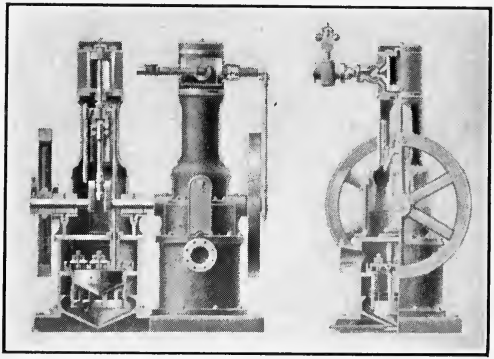

Fig. 115

piston in its descent strikes the water in the bottom. By reason of the conical head and the curved guide this water is projected through the slits into the cylinder above the piston, which immediately after rises, closing the slits and pushing out the water through the valves shown. Sometimes a simple direct-acting steam-pump is used, placed below the condenser, so that the water of condensation can run into its cylinder easily; and one of these surface condensers so equipped is shown in Fig. 116, on which there also appears at the right-hand side a centrifugal pump for circulating water.

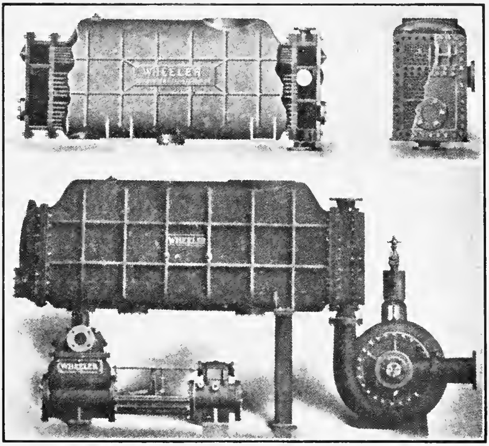

FIG. 116

These centrifugal pumps are much like fans which are fairly common and easily understood. A wheel runs in the casing, and this wheel has vanes or radial or curved arms on it, and by the mere act of rotation the water which enters at the center is thrown off to the circumference, escaping tangentially through the pipe. Centrifugal pumps are commonly used for this purpose because they contain no valves, and permit the use of water that may contain floating matter, such as always occurs when it is taken directly

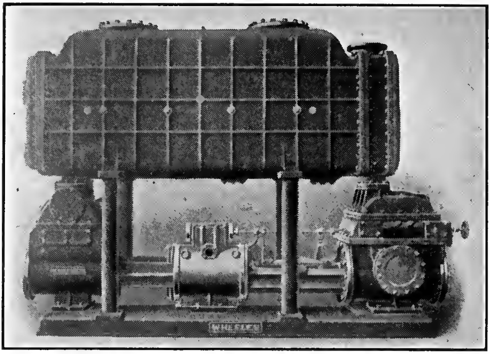

FIG. 117

from rivers. Another condenser of similar form, having the two pumps connected to a single steam-cylinder and located on opposite sides of it, is shown in Fig. 117. A surface condenser with an extension at the bottom for catching water, and provided with an independent pump for removing the water alone, is shown in Fig. 118, while another surface condenser of the vertical form is shown in Fig. 119. This one has a centrifugal pump to remove the water of condensation, but driven by a directly connected electric motor. Some surface condensing equipment set beside steam-turbines for handling their exhaust is shown in Fig. 120, illustrating

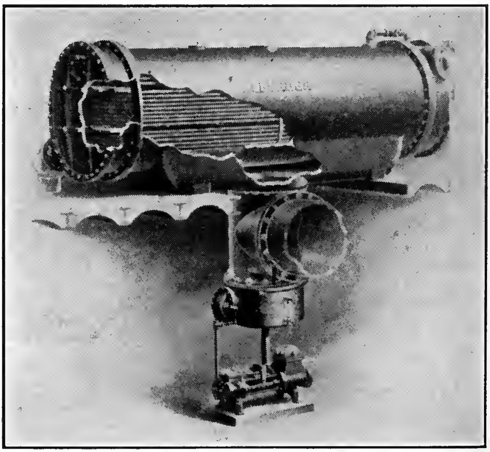

FIG. 118

their relation, and showing, especially in the upper picture, the addition of another or third pump in the operation of these condensers. This is called a dry vacuum-pump, and its business is to pump out of the vacuum chamber all substances collecting there that are incapable of condensing by contact with the cold water tube. All water contains uncondensable gases dissolved in it, such as air, carbonic acid, or the gases generated by decaying animal matter. When this water enters the boiler, the gases are driven off and pass through the engine with the steam, but when the steam condenses, these gases do not enter the water again, but, on the contrary, collect in the condenser vacuum chamber, tending to destroy the vacuum as they collect. When, as in the case of turbines, an extremely high vacuum is desirable, then an additional pump to draw off these gases as they collect is added, and this dry air-pump sucks the gases out, compresses them up to the atmospheric pressure, and discharges them into the air. In the upper part of the figure at the left hand is clearly shown a steam-driven, dry vacuum-pump for removing these gases from the horizontal condenser, which receives the exhaust from the steam-turbine. Another view of a turbine condensing equipment of the same general character is shown in

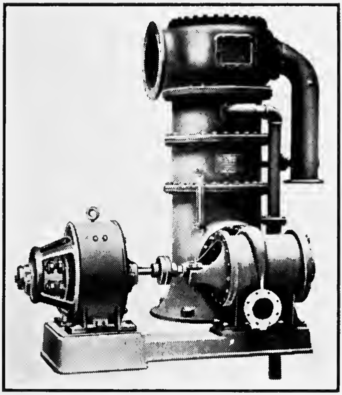

Fig. 119

Fig. 121, representing the Port Morris power station of the New York Central Railroad, supplying current for operating electric trains from the Grand Central to Croton-on-the-Hudson. The vertical turbines discharge their steam into horizontal surface condensers, and centrifugal pumps, one of which is shown in the foreground, circulate water from the East River through the condenser; a vacuum or hot-well pump, not shown, removes the condensation, while a dry vacuum-pump for each condenser, shown at the left, removes the non-condensable gases. When circulating water is not available in large quantities, as is the case in many localities, either the engines must be operated non-condensing, which is wasteful, or a small supply of water may be conserved by cooling it after the condenser has heated it, and so make it available for use over and over again, of course with some evaporation

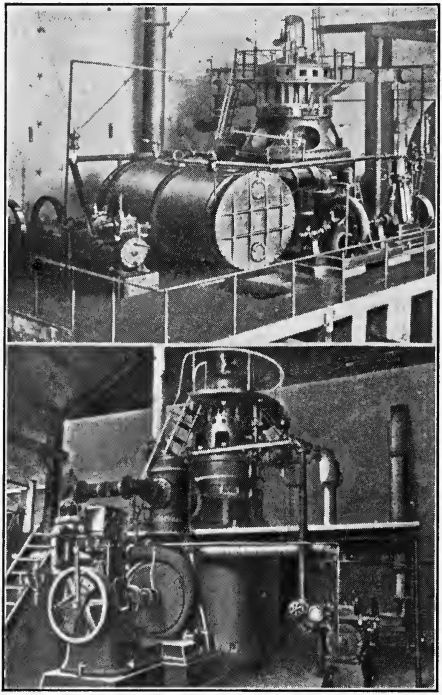

Fig. 120

losses. When water is scarce, it is always a question whether or not the saving in coal consumption due to condensing operation is warranted by the extra cost of water-cooling equipment, but there are many cases where the cooling equipment is entirely justified. To illustrate the nature of this apparatus there is presented

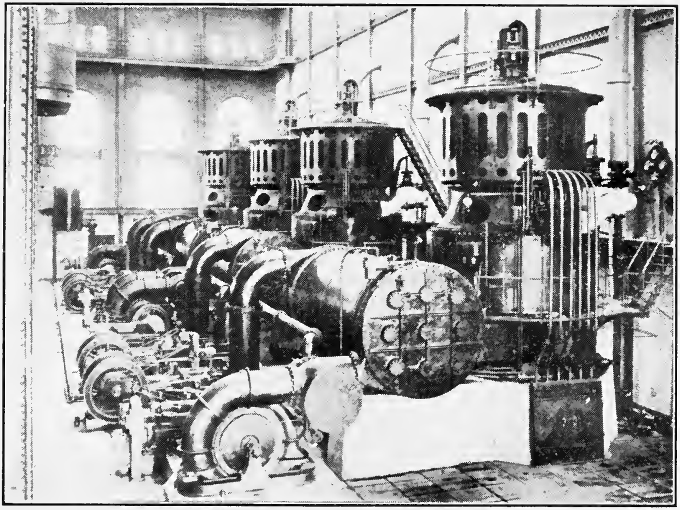

Fig. 121

Fig. 122, showing a cross-section of part of a power house, on the roof of which is placed a cooling tower; the water from the surface condenser below is pumped to this tower and trickles down through it over the surface of wood or tile or metal, as the case may be, while a fan, shown at the side of the tower, blows air up over the wet surface to cool the water to a temperature even lower than the air itself. The cooled water runs down and is used over again in the condenser.

The diagram also shows a vacuum or hot-well pump, returning the condensed steam to the boiler, and the dry vacuum-pump for removing non-condensable gases. This principle of cooling is merely the passing of water in thin sheets over solid surfaces in a tower. Another method is illustrated in Fig. 123, which represents the spray nozzle system. The water issues through specially designed nozzles, forming a fine spray which drops into tanks after cooling while suspended in the air. With many large reciprocating engines, more especially those of the vertical type, another form of condenser is often used, in which the steam and water mix and to which a long tail pipe is added to avoid the necessity for pumping out from the vacuum space the water of condensation mixed with the injection water. This pipe is long enough to resist the barometric pressure, and so is somewhere in the neighborhood of 30 feet high, and at the bottom dips into the discharge water canal. Such a condenser is shown in Fig. 124. The large pipe on the right is the engine exhaust-steam

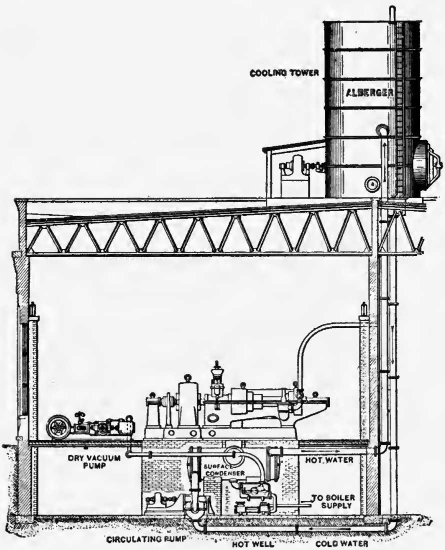

Fig. 122

pipe leading to the condenser, with a branch to the roof in case the condenser becomes inoperative. The pipe at the left nearest the condenser supplies the circulating or injection water, which escapes from the tail pipe at the bottom of the condenser. The pipe leading from the condenser at the top and descending farthest to the left is the dry air pipe. A cross-section of one of these condensers is shown in Fig. 125. Water enters near the top, runs through orifices and over the edges of plates in cascades, dripping through the chamber receiving the steam, condensing it. The waters of condensation and injection together run down the tail pipe. At the top of the chamber the non-condensable gases collect and are pumped out by the dry vacuum-pump. An external view of another form of the barometric type of condenser is shown outside the power house in Fig. 126. This is a very large one, the size of which can be judged by comparing it with the man standing on the ladder at the side. A large vertical engine equipment, with barometer condenser, is shown in Fig. 127, which is a diagram of a cross-section of that part of the house near the engine,

Fig. 123

showing the basement and engine floors. In the basement, it will be noted, there is a small steam-engine driving a centrifugal pump which supplies water to two barometric condensers, which can be recognized by their bulblike form. From these the water runs down through a long curved tail pipe.

Careful tests of engines have indicated

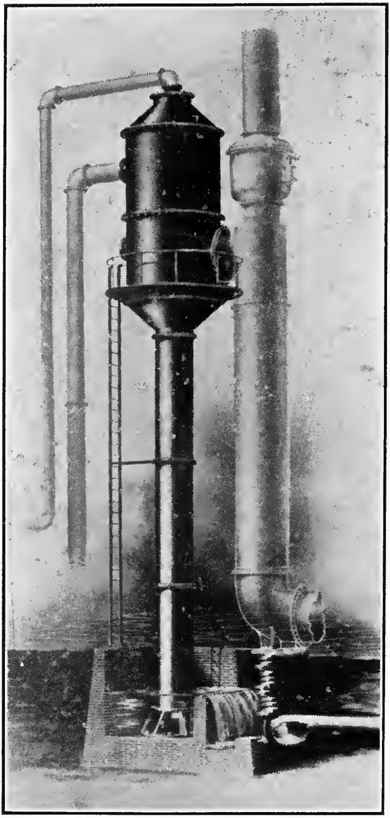

Fig. 124

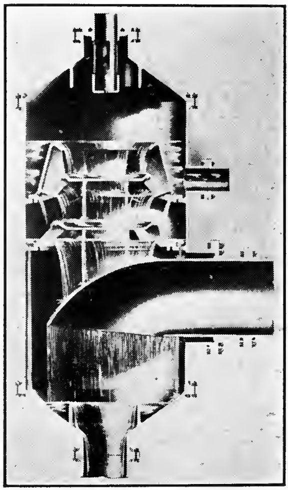

Fig. 125

that a good deal of the steam that enters them does not do any work at all; and this part that does not work is itself divisible into two parts: first, the part which condenses in the cylinder as it enters; and second, the part which leaks past piston or valves into the exhaust before it has a chance to work. Improved machine work and more perfectly designed valves and pistons have reduced the leakage losses a good deal, but it seems to be impossible ever to eliminate all. The reduction of the condensation loss has been a subject

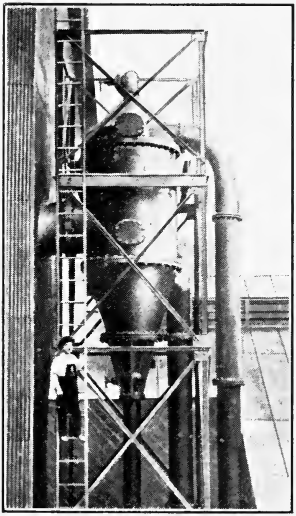

Fig. 126

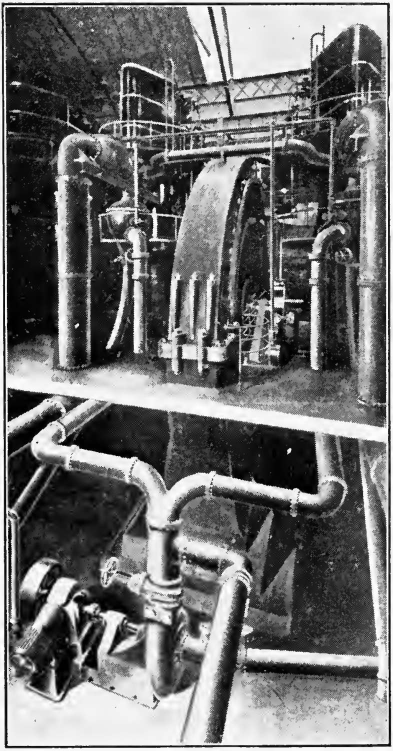

Fig. 127

of study for a good many years. It is greatest when the cylinder is most cold, at the time when the steam enters, and this is the case when the expansion in that cylinder has been greatest, because by expansion the temperature of the steam falls, making the walls colder than they were, and promoting condensation at the next admission of steam. All sorts of devices have been tried, including steam-jackets, but about all that have survived are the use of superheat and multiple expansion. A multiple expansion engine keeps the range of temperature in any one cylinder less than it would be in a single cylinder carrying out the same total expansion. This type of engine, therefore, suffers less from cylinder condensation loss. It has also been found that steam heated more after it is made, or superheated, as it is called, may improve conditions to the extent of 10 per cent or thereabouts, and superheating is being more and more practised for this reason. In Fig. 128 is shown a cross-section of one of the horizontal water-tube class of boilers to which a superheater has been added. This is nothing more than a double row of U-tubes placed in the path of the hot gases at the top of the first pass. Steam passes from the regular drum through these tubes and gets further heated or superheated before it enters the steam-pipe on its way to the engine.

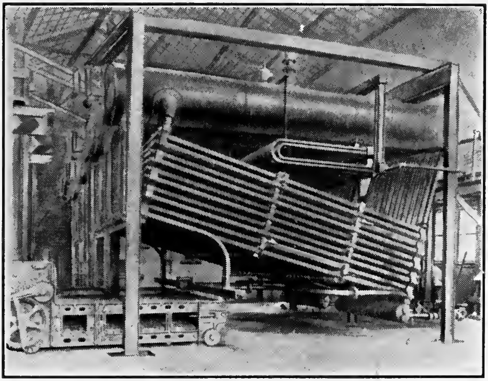

Fig. 128

Analysis of the Average Losses in the Conversion of One Pound of Coal into Electricity

	%	%
1. B. T. U. per pound coal supplied . . .	100.0	
2. Loss in ashes		2.4
3. Loss to stack		22.7
4. Loss in boiler radiation and leakage . .		8.0
5. Returned by feed-water heater	3.1	
6. Returned by economizer	6.8	
7. Loss in pipe radiation		0.2
8. Delivered to circulator		1.6
9. Delivered to feed pump		1.4
10. Loss in leakage and high-pressure drips .		1.1
11. Delivered to small auxiliaries		0.4
12. Heating building		0.2
13. Loss in engine friction		0.8
14. Electrical losses		0.3
15. Engine radiation losses		0.2
16. Rejected to condenser		60.1
17. To house auxiliaries		0.2
Heat supplied and waste returned . .	109.9	99.6
Heat lost in various ways	99.6	
	10.3 %	of heat supplied

After all these improvements of engine, boiler, and auxiliary equipment, and many others of minor importance, each of which is the result of a great amount of patient study, there is yet required on the part of the engineer good judgment to decide whether the expense incurred in saving heat will be warranted by the saving of money, as true economy is measured by lowest net cost of power. This judgment must in every case be based, however, on the heat waste that is to be reduced; and while the various wastes are differently distributed in every plant, yet a fair average of the best is of value.

A comparatively recent analysis of the distribution of the energy supplied in a pound of coal in a large central power station, about as highly efficient as any, is that made by H. G. Stott, superintendent of motive power of the Interborough Railroad, quoted above, and which will show just where the heat goes after the exercise of best skill and judgment in the selecting and managing of the apparatus.

From this it appears that 60 per cent of the heat of the coal is finally discharged in the condensing water and nearly 23 per cent to the stack for the maintenance of draft, these two together aggregating about 83 per cent of the heat in the coal. No way has ever been found to reduce this heat that must be delivered to the condensing water. It is an essential characteristic of the steam system; and the fact that steam in condensing, at however low a pressure, does give up to the condensing water so large an amount of heat, constitutes a final limit of efficiency inherent to this system. If the system were non-condensing, a larger per cent would have been discharged into the air than is received by the condensation water. With regard to the stack loss, this can be entirely eliminated, but this elimination would mean the substitution of some other means of producing draft and no means has as yet been found that is as cheap as the loss itself. In other words, the operation of fans or any other devices for maintaining draft has been found to cost more in the long run than to build a chimney and allow this 23 per cent of the coal heat to escape up it to produce the draft needed to burn the coal at a suitable rapid rate.

It is not so much the object of engineers to reach high economy in the use of coal; it is not so essential that the greatest amount of coal energy be turned into work or that in the use of coal for power the heat wastes be reduced to a minimum. The question is really far broader than this. The problem to be met is strictly and properly that of minimum waste, but minimum waste of everything, not only coal or water, but labor and investment. It would not pay to build a power plant costing four times as much as existing plants, even if the coal consumption could be reduced to a half of what it is, and this fact can only be appreciated by some figures. According to the last census report the average output of the central power stations of the United States was about 25 per cent, or one-fourth of their capacity. Suppose that these stations cost, as the better ones do, $120 per horse-power to build, and that there be set aside each year a certain sum for depreciation, from which worn-out apparatus is to be renewed and the plant perpetuated, and another sum yearly representing the interest on the investment; another sum for the salaries of officers and superintendents; still another for insurance and taxes and for similar items, altogether amounting perhaps to 12 per cent per year on the first cost. Then if this plant worked all day and every day at full load there would be charged against the cost of power a fixed sum of $14.40 per year per horse-power. If the plant, on the contrary, worked on the average to only one-fourth of its capacity, then this fixed charge per horse-power would be four times as much as before, or $57.60. It may be assumed that in stations of the kind under consideration this fixed investment charge is fully as large as the cost of coal and labor and other supplies put together, from which it appears that a saving of 10 per cent or 15 per cent in coal will affect the cost of power not as much as 5 per cent, even if no additional apparatus were required; but if the fixed and operating charges on needed additional apparatus were to be included, there might actually be a loss incurred and power cost more than without the additional equipment when wasting some coal. This would more surely be the case if much more additional labor were required to take care of the additional apparatus. In a comparatively recent discussion of this point, Mr. F. G. Clark, superintendent of the Pennsylvania and Long Island R. R. power station in Long Island City, gave the following figures for various average outputs of power stations from 100 per cent down to 20 per cent of their capacity, the figures applying to a steam-turbine station in which the fixed charges are less than for a piston-engine station, because the turbines are themselves considerably cheaper than piston engines. The power is here measured in kilowatts, an electrical unit equivalent to one and one-third horse-power.

POWER COST DISTRIBUTION WITH AVERAGE STATION OUTPUT

Average output of station	100%	80%	60%	40%	20%
Total cost per K.W. year	$35	$40	$49	$65	$100
Investment charges . .	26%	29%	31%	36%	46%
Coal charges	53%	54%	53%	49%	39%
Labor	12%	9%	9%	9%	9%
Miscellaneous	9%	8%	7%	6%	6%
	100	100	100	100	100

It will appear quite evident, from what has been said above, that not only has the scientific study of the reduction of heat waste in steam-power systems been put upon a firm and substantial basis through the assistance of thermodynamics, and that engineers are engaged in patiently calculating, predicting, testing, and recalculating possible improvements, but that their attention is also directed toward the broader questions of net economy. Its attainment is a combination of strictly technical with business problems, and involves the use of methods that permit of intelligent judgment of what should be done before it is done, and of the true economical value of new proposals for doing old things.

Such inventors as those whose work caused the industrial revolution have no equally important place in the modern social organization. Their knowledge was confined to the wheels, rods, and cylinders referred to by the historian, whereas to-day, while we are still somewhat dependent on such men, real progress can be attained only by a far higher order of direction, requiring trained engineers who must be at once practical mechanics, scientists, economists, financiers, and managers of men.

V

PROCESSES AND MECHANISM OF THE GAS-POWER SYSTEM

It was not until the establishment of the relations of heat to work, and the conditions for transforming the former into the latter, as embodied in that body of the principles of physical laws known as thermodynamics, that the great possibilities of the gas-power system were recognized. In the steam system of securing work from heat, the heat is added to water, turning it into high-pressure steam; the steam then acting like a compressed spring can either give itself a velocity as in the turbine, or push on a piston as in the piston engine. No matter which way it acts in doing work, much of the heat put into the steam in making it is carried away by the exhaust steam, estimated at about 60 per cent even when working with a good vacuum, and considerably more when the exhaust steam is discharged into the atmosphere without condensing. No matter how perfect the steam-engine mechanism, these conditions, together with others noted, impose a low limit on the efficiency or a high limit on the waste heat. As a matter of fact, no matter what the system of changing heat into work, there will be limits to the possible performance of even a perfect mechanism, but the limit is different for different systems. The gas system has a much higher possible efficiency limit than the steam system, and one of the greatest contributions of thermodynamics is the determination of this fact, and the establishment of a method of calculating the limit of efficiency, or the maximum possible amount of heat that may be transformed into work by adding the heat of the fuel to gases instead of to steam, using the springlike action of gases to do work on pistons, much the same as does steam in piston engines.

A mass of any gas, such as air, or the gaseous products of combustion, will, if confined in a chamber and there heated, suffer a rise in pressure; and this gas of increased pressure may be used to push a piston, expanding as the piston moves and continuing the push as long as the pressure lasts. Similarly, if the heating be continued as the piston advances, the pressure may be maintained higher or longer and the push augmented. Early attempts, and even such comparatively recent ones as were made by Captain John Ericsson during our Civil War period, to embody such gas heating and expanding processes in mechanisms to constitute a gas or hot-air engine, based on the heating of air inclosed in and between cylinders by a fire outside, amounted to very little because only a small portion of the heat of the fire actually reached the inclosed air, and of this small amount only a fraction was converted into work. A still more serious difficulty, however, was encountered in the rate of working, as air can be heated only very slowly through plates, so that the engine had to be enormously big to give a little power and prohibitively expensive as a consequence. After many trials, most of them unsuccessful, two basal principles were finally recognized: first, that some faster method of heating was necessary; and second, that air or other gas previously compressed by a piston before heating is capable of yielding more work for the heat it receives than without compression. Heat must, therefore, be added directly to the gas without passing through plates; and by compressing the gas higher and higher before heating, the efficiency, or work per unit of heat, may be extremely high, approaching even 80 per cent, and this may be realized if no mechanical difficulties are encountered in carrying out the process. Unfortunately there are such difficulties, but 35 or 40 per cent has actually been realized by one of these gas engines.

Means for securing the rapid heating needed are found in the process of combustion itself, for there is no more rapid method of making cold gases hot than by choosing such gases as will combine chemically or burn, heating themselves as the combustion proceeds. Early attempts were made to use coal fires; air pumped through a fire inclosed in strong, tight chambers became very hot almost instantaneously, and the problem seemed to be solved. However, the difficulty of regulating the fire, feeding coal, and removing ash when the furnace was bolted inside of thick metal vessels, and the cutting action of the ash dust on the cylinder walls, soon showed that the mechanical difficulties of this process were too serious. Attention was then turned to an older combustion process, which, for some unexplainable reason, except perhaps an unfounded fear of destruction, had not received much attention, the process of explosive combustion or just explosion.

All fuel, whether solid coal, liquid oil, or gas, consists of only a few primary combustible substances or chemical elements, which when combined in various ways give to natural fuels their special form. The two important combustible elements are: first, solid black carbon, familiar in a variety of forms itself, as lamp-black, charcoal, or diamond; and second, gaseous hydrogen, the lightest gas known and so used for inflating balloons, making them able to float in air. All sorts of carbon and hydrogen compounds are known, several hundred in number, some existing as gases, some as liquids, and others as solids, but all useful as fuel, — fuel in the sense that when heated in the presence of gaseous oxygen they will combine chemically, giving out heat very rapidly and turning into two other gases: first, carbonic acid gas, the gas used in charging soda water; and second, water vapor. In the formation of carbon dioxide one particle of solid carbon unites with two particles of gaseous oxygen, making one particle of gaseous carbon dioxide; and in the formation of water vapor two particles of gaseous hydrogen combining with one particle of gaseous oxygen make one particle of very hot water vapor, or superheated steam, which, when cooled, may become liquid water. If hydrogen be mixed with oxygen before igniting in just the right proportion, so that after combustion no hydrogen remains unburnt and no oxygen is left unused, then this combustion will take place in that peculiar way described as explosive. This explosive property is possessed by a substance or mixture when after lighting it at one spot the flame will itself travel quickly through the whole mass. A room filled with such a mixture and ignited at the center would exhibit a beautiful phenomenon if it could be observed without danger; the flame would start from the central or starting point and move with equal speed in all directions so that there would be formed a true ball of fire rapidly increasing in size until all the mixture had been burned. Of course, this rapid heating would raise the pressure, blowing out windows and possibly also the walls, as they are not constructed to resist such pressure; but if carried out in strong iron chambers, the only effect would be a mass of high-pressure hot gas formed in almost the wink of an eye. This explosive property is peculiar to any sort of intimate mixture of fuel and oxygen if the proportions are right, and as air is one-fifth oxygen, the property also applies to any intimate mixture of fuel and air. It makes little difference whether the fuel be in the form of fine coal, charcoal dust, or even flour dust, fine liquid fuel spray such as an atomizer may produce, or a combustible gas such as is used for lighting, produced in any convenient way, or the vapor of a liquid fuel such as might be obtained by heating gasolene. In every case, however, the proportions of fuel to air must be kept within proper limits. It is explosive mixtures of air and gaseous fuel, or air and oil spray, or air and oil vapor, that are now used in gas engines to produce the rapid heating of confined gases, and these gases are always compressed in cylinders by pistons before ignition, the hot high-pressure gases resulting from the explosion pushing on the same piston to do the work on the return stroke.

The modern gas-engine, no matter whether its fuel supply be primarily gas, oil, or coal, will involve apparatus whose principal function is to create from the fuel as it exists an appropriate explosive mixture for use in cylinders. The explosive mixture that actually exists in the gas-engine cylinder consists of air mixed with gaseous fuel, or with the vapor or mist of liquid fuel, in certain proportions, with which active mixtures there will be certain neutral substances like carbonic acid or water vapor derived from a previous explosion. The first essential process in the operating of a gas-engine is, then, the making of a mixture of appropriate sort, and this process in turn involves many secondary processes, some of which will be traced. When the mixture is made, it must be introduced into a cylinder and there treated or subjected to certain processes, the first of which is compression. By the movement of a piston the mixture is forced into a small space at one end of the cylinder, causing the pressure to rise, and at some high compression pressure, thus developed by the piston alone, the fuel, intimately mixed with all the air it needs for its combustion and no more, will be ignited by either hot metal or an electric spark. The result of the ignition of this highly compressed and confined explosive charge will be not a noise, not a disruption, nothing more complicated than a rapid heating of the entire mass as the flame passes through it, accompanied by a rise of pressure. That the flame will pass through the whole mass of the confined mixture is the prime characteristic of explosive mixtures, whether they be of this gas-engine sort or of the gunpowder sort. Gunpowder is a mixture of fuel and the oxygen it needs to burn it, all in the solid form. There are rapid-burning powders and slow-burning powders, and we have learned how to apply powder of varying rates of combustion to projectiles of different weights, sizes, and shapes, to secure the most effective driving of the projectile, by giving it the highest muzzle velocity with the least tendency to smash the gun or to dissipate energy. Compared with most gunpowder, explosive gaseous mixtures, such as are used in engines, are very slow-burning indeed; and the rate at which they burn, or the rate at which the flame travels through them from particle to particle, is technically called the rate of propagation. As a consequence of this rapid heating of the confined gases, the pressure very materially rises to perhaps twice what it was before, occasionally $4\frac{1}{2}$ times, rarely 5 times, reaching maximum values of from 150 to 600 pounds per square inch, and the explosive combustion has performed its useful function. The explosive combustion has rapidly caused the pressure of the gases to double, quadruple, or more, and in a short time after compression. This high gas pressure acts on the same piston that originally compressed the charge into the confined space, technically called the cylinder clearance, or explosion chamber, or breech end. On the return stroke following compression, the high-pressure gases will drive the piston back, and in so doing ever so much more work will be done by the hot gases than was required to compress the cold gaseous mixture, and the difference is the useful work. The burnt gases, when the piston has reached the end of the stroke, must be expelled, and the whole series of operations of making the mixture, introducing it, compressing, exploding, expanding, and expelling it will proceed automatically by means of mechanism designed with this end in view. The gas-engine is then primarily a cylinder with a piston and certain means for making proper mixtures, getting them into the cylinder, treating them properly after they arrive, getting the burnt gases out, and doing it

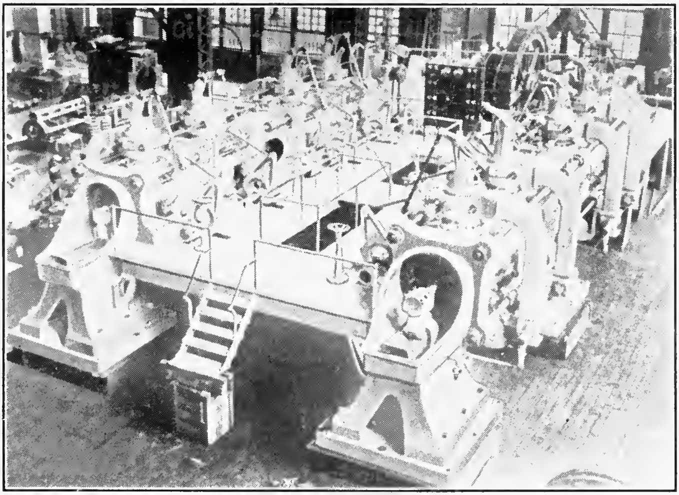

Fig. 129

as often as may be necessary, as fast or slow as may be necessary, and using as much mixture as may be necessary to do the required work. There must also be some element of control, so that if much work is required of the engine much work will be done on the piston by the use of much mixture, while if little work is required by the engine only a little mixture will be used. Now all the complicated mechanisms that are seen about gas engines, and which are well indicated by Fig. 129, are there for just these things, as well as perhaps for a few others, such as lubrication, cooling of the hot walls to prevent them twisting out of shape and to prevent the lubricating oil from burning up, but not much more. It is hard to believe that there is not much more than this when first viewing a large gas-engine, which seems to be a mass of complicated parts, the duty or function of which is by no means clear or apparent.

Before proceeding to study more in detail the elements of the essential processes of making mixtures

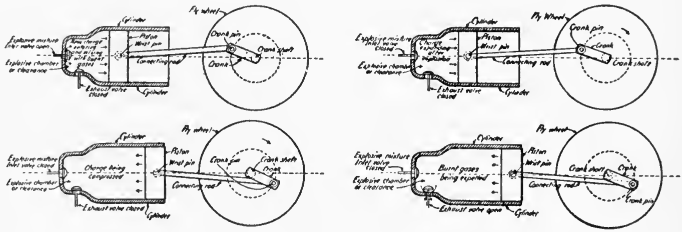

Fig. 130

from natural fuels, proper in kind and amount, it will be better to trace the succession of processes most intimately associated with the cylinder, piston, and valves, afterwards returning to the making of the mixture before it reaches the cylinder.

A diagram of a piston and two valves, one for admission and the other for exhaust, is shown in Fig. 130. The piston is attached direct to the usual connecting rod, crank, crank-pin, and crank-shaft. It appears from the upper left-hand diagram that the piston is moving outward, drawing the mixture into the cylinder through the open inlet valve, which is formed much like a mushroom and is called a poppet valve. Just how the proper mixture is made is a matter of no importance at this time. The drawing in of the mixture occupies the whole of this suction or charging stroke. Under the influence of the fly-wheel the piston returns as is indicated in the lower left-hand diagram, compressing the mixture with all the valves closed. This compression continues for this entire stroke, which is, therefore, called the compression stroke, and at the end of this stroke ignition takes place with a resultant pressure rise, previously described. This is followed during the next out stroke by the expansion of the gases, as shown in the upper right-hand diagram, all valves still remaining closed for this entire expansion stroke. Toward the end of this expansion stroke the exhaust valve is opened and the gases begin to rush out. The piston then returns, expelling the rest of the burnt gases or nearly all of them, through the exhaust valve, which is open. Of course, some burnt gases must be left behind, as much as will fill the explosion chamber or clearance space. Thus, the succession of processes occupies four strokes, giving to such an engine the name of four-stroke-cycle or four-cycle engine, which may be examined again with a little more detail in Fig. 131. Here both valves have vertical stems. A water-jacket is shown surrounding the cylinder; a more usual form of piston is shown with the pin at the middle of its hollow interior, it being itself a cylinder open at one end and closed at the other. The diagram shows eight positions of the piston and valves, two for each stroke, one illustrating the relation of the parts at the beginning and one at the end. Thus, starting at the upper left-hand corner and passing down, the suction stroke is shown beginning with the inlet valve open and ending with it closed, the valve remaining open all the intervening time. The compression stroke is

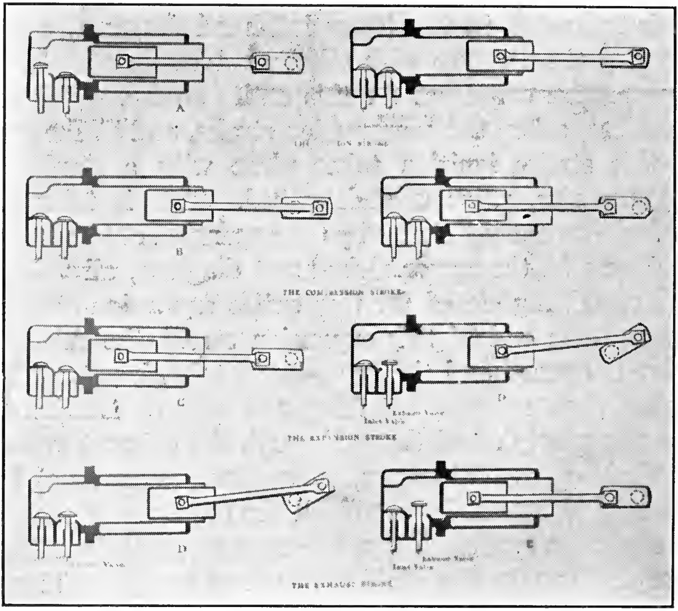

Fig. 131

shown with both valves closed, both at the beginning and end and for all the time between. The expansion stroke is shown with both valves still closed at the beginning, remaining closed until the crank has reached the angle shown, at which point the valve opens so as to completely relieve the cylinder pressure before the piston starts back. The exhaust, therefore, really occupies more than a full stroke because it begins before the completion of this remaining part of the expansion stroke and occupies the whole of the next stroke. In still greater detail some of the mechanism is shown in Fig. 132, representing a cross-section through one of these four-cycle horizontal single-acting engines. Here it appears that the piston has webs under its head to strengthen it. It has spring rings around part of

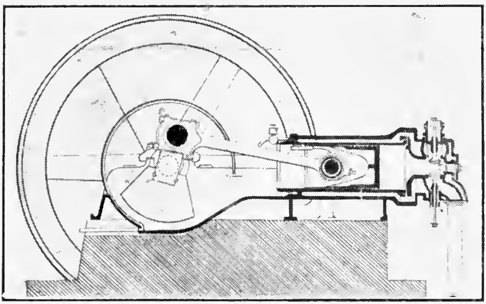

Fig. 132

it, so formed as to prevent the high-pressure gases leaking out. There is water all around the cylinder and around the valve chambers. The valves are shown with springs to close them and keep them closed all the time that some other piece of mechanism is not pushing them open, and between the valves is shown the igniter at *F*, which is nothing more than a device for making an electric spark at the proper time; besides these features there are, of course, a frame, crank, crank-shaft, a counterweight, oil-cups, oil guards, and fly-wheel. A small vertical high-speed engine is shown in Fig. 133, in which there is the usual piston with piston rings, two valves, one above the other, the upper one being for inlet and the lower one for exhaust, both provided with springs to keep them closed, but the bottom one having in line with its stem a push rod against which a cam may strike, the cam being only a lump on the small auxiliary shaft. When the cam does strike the push rod, it will rise and the valve will open. Both valves might be so operated, and in most large engines are operated by such cams, but in some small engines, such as this, to simplify the engine the inlet valve has no cam to operate it. It is just held to its seat with a light spring. When the pressure in the cylinder due to the suction stroke of the piston becomes less than atmosphere, or less than in the mixture chamber, that difference in pressure on the two sides of the valve forces the valve open. At the end of the suction stroke the difference in pressure is relieved; in fact, it would reverse on compression so that the valve promptly closes. The frame here shown is of different form from the previous one, being intended for attachment to the frame of an automobile. The cylinder has no water-jacket, but has in its place a number of ribs. The heat from the cylinder will be conducted out along these ribs and radiated in all directions from them; air blast fans are sometimes added to facilitate the cooling of these ribs and the

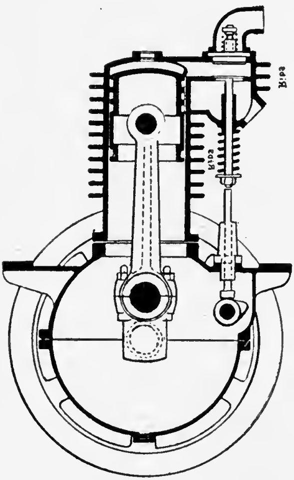

Fig. 133

cylinder. This is the characteristic of the air-cooled type of motor, which is only useful in small sizes, because even the most effective ribs cannot produce good enough cooling for large cylinders; in them water is always used. In the next figure (Fig. 134) there are shown three views of a large horizontal engine in which the operations take place on both sides of the piston,

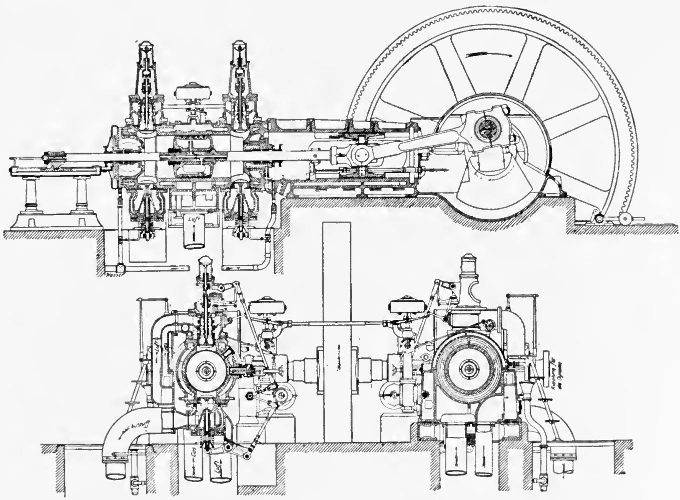

FIG. 134

making it a double-acting engine. The piston in this case is fastened to a piston rod, which passes through holes in the heads of the cylinders, these holes being packed by stuffing boxes to prevent the leakage of gas. Such piston rods and pistons would get red-hot in a short time if not cooled, as explosions take place regularly on both sides of them, so they are made hollow and water is circulated through them just as water is circulated around the cylinders and valve chambers. Valves are shown as in the previous cases, always of the poppet form and moved by cams through rods and levers. Inlet valves are on the top and exhausts at the bottom; but here, the engine being double-acting, there are two sets of valves, one for each end of the cylinder, and all of more complicated structure to give the necessary strength and avoid cracking from the severe internal heat. When two cylinders are set in

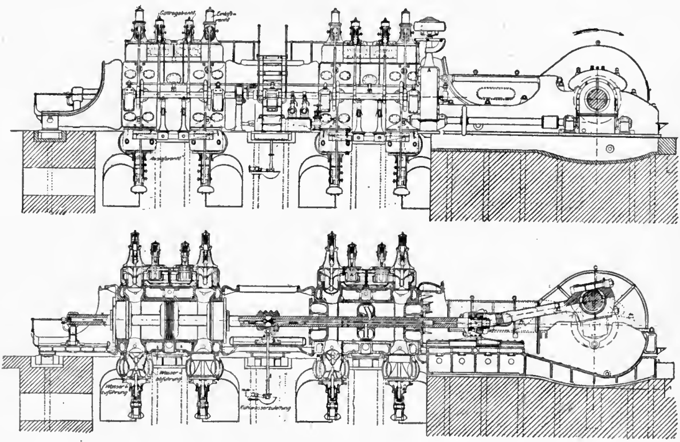

Fig. 135

line, the engine is technically known as a tandem double-acting engine, and Fig. 135 illustrates a section of one of these engines of large size, the piston and rod of one cylinder being also shown in section while the other is not. Two sets of double-acting cylinders, side by side, and working on the same crank-shaft, constitute the standard arrangement for large engines and is called the double-acting tandem twin engine. Two such engines of about 1700 h. p. each are shown in Fig. 136, as installed in the power plant of the Milwaukee

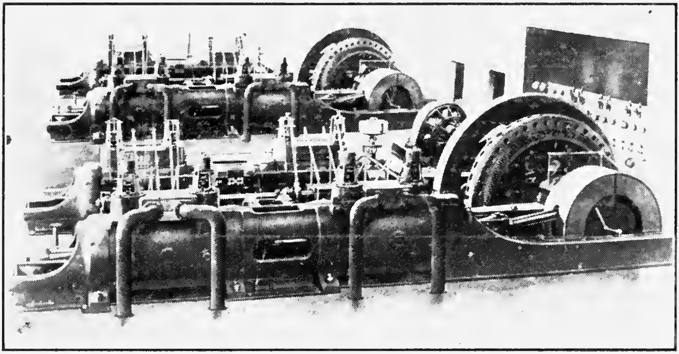

Fig. 136

Railway. A closer view of one cylinder of another large engine of this type is shown in Fig. 137, showing clearly the valve gear and the auxiliary side shaft from which it derives its motion. At the new steel plant at Gary, Indiana, there will be provided over a hundred thousand horse-power of these large gas-engines, one group of which, consisting of a row of three thousand horse-power units, is shown in

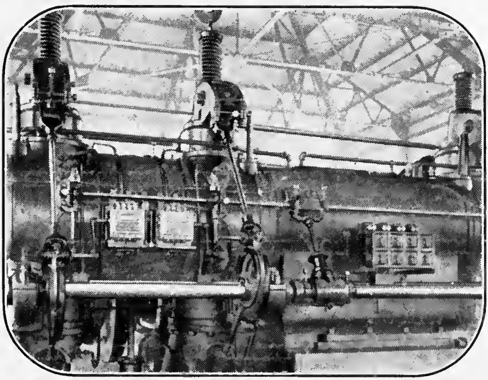

Fig. 137

Fig. 138. The man standing on one of the cylinders will serve as a scale by which the size may be judged. All of these engines described are four-cycle engines, that is to say, for every stroke used in drawing in a charge, three other complete strokes are necessary, one to compress, one to expand, and one to exhaust, so that with such large double-acting tandem engines as have just been examined, there is an explosion in each chamber every fourth stroke, or with the four

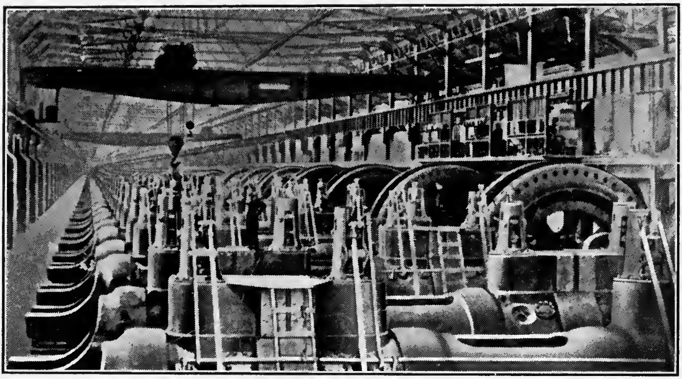

FIG. 138

chambers of a double-acting tandem engine each stroke of the piston is a working stroke, and for a twin engine there will be two impulses forward and two impulses back, or four total impulses for each revolution of the fly-wheel.

Engines are made to operate under other cycles so far as the cylinder functions are concerned. For example, Fig. 139 illustrates an engine that does not have as many valves as the others so far examined, but it has something in place of them. It is a two-cycle engine, so called because it can carry out all the necessary series of cylinder operations in two strokes instead of four. This is done by utilizing the other end of the cylinder, which in a single-acting four-cycle engine is idle, or, what is the same thing, by utilizing a closed crank case, or, what is likewise equivalent, in very large engines by adding pumps, one for air and one for gas. The function of these pumps, or the crank case, if it is

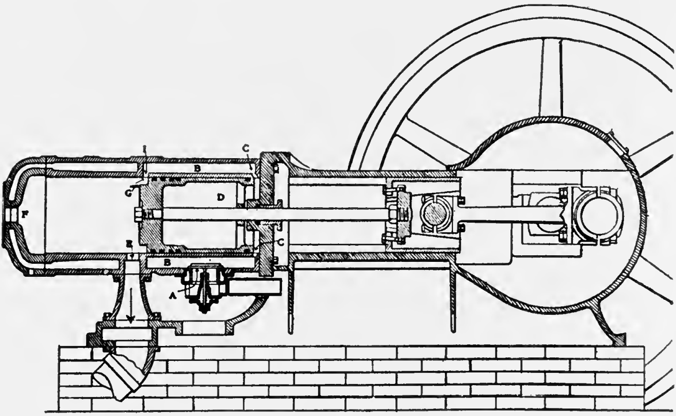

Fig. 139

closed, or the forward end of the cylinder, if it be closed up, is to get ready the mixture so that it can be puffed into the cylinder during a portion of the stroke without using up a whole stroke. Referring to Fig. 139, it will appear that the piston is fitted with a lip *G*, which, in the position shown, is just underneath a slot or port in the cylinder marked *I*, communicating with the passage *B*, *C*, *D* to the forward end of the cylinder and communicating likewise at the bottom of *B* with an inlet valve *A*. This inlet valve is of the automatic sort, having no cam to open it. Just at the bottom of the cylinder there is another slot *E*, connecting with the exhaust pipe. Imagine the piston to move to the left, then whatever is in the cylinder when the piston covers the ports *I* and *E* will be compressed. At the same time there will be a suction in the chamber *B* and *C*, lifting the valve *A* and allowing the mixture to follow in behind the piston in the chamber *D*, while the compression is going on to the left. When this compression is all over, the igniter, placed at *F*, will fire the charge, the piston will move to the right, the hot gases on the left-hand side expanding, and compressing the mixture on the right-hand side. When the piston has reached the point of uncovering *E*, the high-pressure hot gases will rush out through the exhaust pipe, as indicated by the arrow. Immediately after, the top of the piston will uncover the port *I*, communicating with the fresh mixture at *B*, which will rush in because it is compressed and the pressure in the cylinder is now low, having been relieved through *E*. As the mixture rushes in it will be deflected by *G*, the lip on the piston, and will so be deflected sidewise to the end of the cylinder and there be reflected back towards *E*, pushing out in this way much of the burnt gases that may be left. Thus, exhaust is accomplished and a new charge fed in during the time it takes for the piston to uncover the port *E* and get back again so as to cover it up. The whole working series of operations is accomplished in two strokes, which fact gives the two-cycle engine its name.

All modern gas-engines subject the mixture after it goes to the cylinder to essentially the same series of processes, however much they may differ in other ways structurally. The principal differences are to be found in the means for making the mixture, adjusting the quantity of mixture needed each stroke, and preparing natural fuels by vaporizing liquids and gasifying coal. The first vital function of any gas-engine mechanism is to make proper explosive mixtures, and special apparatus is designed with this in view; for the mixture is to the gas-engine what the steam pressure is to the steam-engine and the water pressure to the water-wheel. Chemically speaking, a mixture is proper when it contains exactly the amount of oxygen necessary to burn the fuel, no more and no less, and when at the same time, by reason of perfect mingling, each particle of fuel is in direct contact with its own share of oxygen. Since the oxygen must be derived from the air, such perfect mixtures cannot be obtained, because each particle of oxygen carries with it, roughly, five times its own amount of nitrogen, which is neutral or inactive. The effect of this nitrogen is not, however, serious, as it only retards the rate of propagation or increases the time of explosion. Much neutral will make a mixture too slow-burning to be useful, but fortunately there are conditions which accelerate the combustion so that even very weak mixtures are still useful in engines. As already explained, explosive combustion is spherical in character, inasmuch as with the flame moving at a fixed speed in all directions the fire exists at any moment on the surface of a sphere. This in itself results in accelerated combustion, because as the surface of a sphere grows faster than its diameter, more mixture will be burnt at each succeeding moment than the preceding, even if the rate of propagation or increase of diameter of the sphere is constant.

This spherical sort of regular acceleration of the rate of combustion is of great importance in engines, but the uniform flame propagation with which it is associated does not maintain for long. There is an even greater tendency to accelerate, due to the elastic nature of gases. It is plain that with the first little burst of flame the pressure will momentarily rise at that spot higher than at neighboring spots, and so a sort of pressure impulse or wave will be transmitted through the mass much as sound travels through the air. It is found in actual observations on mixtures that while at first the flame movement seems to be uniform, it shortly becomes oscillatory. This may be due to the fact that in mixtures of high pressure the flame travels faster, so that at the crest of the little wave started from the first burst of flame there will be a momentary acceleration of combustion followed by a retardation as the crest changes into a hollow, and then as at the point where a hollow existed a crest appears, there will be alternately slow and fast flame movement. The wave thus formed will meet a returning wave, a wave that has been sent to the limits of the chamber and reflected back. It seems at times as if such old reflected and new advancing waves superimposed their crests, producing localized spots of very high pressure and very fast combustion. Such localized fast combustion is detonating in character and its condition is designated as the explosive or detonating wave.

While the addition of neutral to a mixture will cause the whole combustion to proceed more slowly and too much neutral will prevent an explosion taking place at all, yet very weak mixture can be successfully burned at a proper rate by previous compression. A mixture so weak that it will not burn in the open air will, if compressed enough, burn quite readily, so that a mixture that contains so much neutral as to be non-explosive may be made explosive if it is previously compressed, and engines may successfully use gases so weak as to be otherwise useless.

If there is more air present than the fuel needs, all the excess may behave the same as a neutral, because it is inactive. As a consequence, mixtures with more air than is chemically needed are explosive, as well as those chemically correct, up to a certain limit, of course. On the other hand, mixtures that contain more gas than the air present can burn are likewise explosive up to another limit, the extra gas behaving as neutral because it is inactive. Mixtures, then, may be explosive through quite a wide range of proportions of air to fuel, or quite a wide range of proportions of active and inactive diluent materials. The range of proportions of explosive mixtures is greater the richer the original fuel. Thus, for kerosene, gasolene, natural gas, and similar rich substances, the range of proportions of air to fuel is very great; while with blast furnace gas, which is a very weak gas, the range is not so great. In every case, however, the range of explosive proportions becomes wider and wider the more the mixture is compressed. Whenever fuel is in excess, it is entirely wasted, but excess air can do little harm if the mixture will still explode.

The piston speed of the engine is zero every time the piston is at the end of the stroke, because it comes to a dead stop; the speed rises to a maximum somewhere about mid stroke and falls again to zero, so that it is constantly and regularly changing. It is found in practice that the best results are obtained when the combustion is completed as nearly as possible before the piston begins its working stroke. It would seem from this that complete combustion should take place between the time when compression is completed and when expansion should begin, that is to say, it would seem as if the explosion should be completed in zero time or be instantaneous. Now, as a matter of fact, the conditions are not quite so severe, for it is found that by igniting the charge a little before compression is finished, the flame acceleration which is natural to the mixture will be in most cases quite enough to practically complete the combustion before the expansion stroke begins. If ignition were delayed much, the piston speed would have increased so much that in a certain sense the combustion would never catch up with it, and instead of getting high explosion pressures at the beginning they would be low; instead of getting most work from the heat by expanding after complete combustion, there would be obtained a less amount of work because expansion would be proceeding during combustion. The time of ignition, therefore, must be carefully adjusted, first with respect to the piston speed, and second with respect to the natural rate of combustion of the mixture. A mixture which is too slow burning for a given piston speed may be accelerated by increase of compression, and to a certain extent this adjustment can be made. There is, however, a limit to this increase of compression. The limit is imposed by the natural temperature of ignition of the mixture. As the mixture is more and more compressed, so does it become hotter throughout its entire mass; sometimes it will get hot enough to ignite itself, independent of the spark. This is called self-ignition or preignition. It is found in actual work that, while a weak mixture can be made faster burning by compression, it cannot be made as fast burning as a rich mixture because the compression cannot be carried far enough. It ignites itself before as much compression as might be desired has been attained.

It might seem from these arguments that it was desirable to highly compress only weak mixtures so as to make them burn fast enough, but as a matter of fact it is desirable that we should compress all mixtures as much as possible, — as much as the tendency to self-ignite will allow. One of the principal propositions concerning engines of this class, solved by the mathematics of thermodynamics, is that the more the compression the higher the efficiency and without limit. An engine, then, using a mixture that permits of high compression, whether it be rich or poor, should by reason of the high compression alone give a high efficiency, and within certain limits this is found to be true in practice. It is also found that our desire for high compressions and high efficiency is limited only by the temperature of ignition for the mixture, and in general, though not always, the richer mixture will stand the least compression. More particularly is it true that certain hydrocarbon fuels, such as kerosene and gasolene, will stand the least compression before ignition, and likewise mixtures with free hydrogen will stand less as a rule than mixtures without hydrogen, other things being equal. The limit of compression, then, is set in practice by the temperature of ignition, and this in turn depends upon the nature of the fuel, so that with different fuels it is not possible to get quite the same efficiency, because equally high compressions are not permissible.

So far as the engines themselves are concerned, these physical properties of explosive mixtures are valuable in two ways: first, in dictating how the mixtures may be treated in cylinders; and second, in explaining things which happen but which were not foreseen. A knowledge of such mixtures is quite essential to a correct understanding of the gas-engine. We are, however, concerned principally with one part of the application of this subject. The engine will run properly and best when its mixture is most constant, when the engine gets the proper quantity of this mixture, and when the mixture received is compressed as highly as possible without forcing it beyond control.

As previously stated, by far the greatest variation in the mechanism of engines, and by far the greatest complication in their mechanism, is found in that part of the valve gear which is concerned with the proportioning of mixtures, the actual mingling of the parts of the mixture, and with the adjustment of the quantity in proportion to the work to be done.

Mixtures are proportioned in engines as they are drawn in. In other words, they are proportioned as they are made. The suction stroke of the piston starts a movement of gases towards the cylinder, and as there will be two sources from which to satisfy this displacement, one the atmospheric air and the other the fuel gas-pipe, it is plain that if a valve in the fuel gas-pipe be closed and the air opening be free, nothing but air will enter; or if the air valve be closed and the gas valve opened, nothing but gas will enter; and so if a valve be opened in both the air and the gas ports, both air and gas will enter and the proportions will depend upon the relative openings. This is the primary principle of proportioning used, two openings, one for air and the other for gas, and means for adjusting these openings so that the relative amount of air and gas can be adjusted. These valves for adjusting the proportions are generally independent of the valve controlling the mixture admission to the cylinder, and may themselves or in conjunction with some other device be called the mixing valves or proportioning valves of the engine. In Fig. 140 is shown an inlet valve attached to the cylinder casing, with gas and air ports, the upper one being for gas, each port provided with a damper valve. On the suction stroke of the engine the sliding sleeve attached to the valve stem will be pushed down with the valve, and the holes in the casing and sleeve will register. In this position the gas drawn past its damper will pass through the port from the inner to the outer

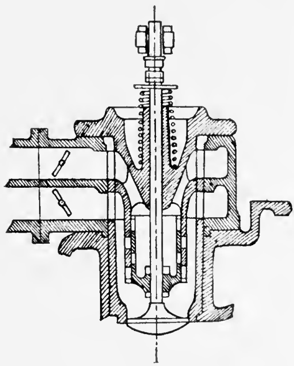

Fig. 140

chamber, meeting air from the other port, and the mixture will enter the cylinder by passing the poppet valve. This sliding sleeve is added to the inlet valve stem to prevent the gas, which is generally under some pressure higher than atmosphere, from flowing into the air passage when the piston suction ceases between changing strokes. If this were omitted, there would be a tendency for the mixture to become too rich at low loads or at intervals between suctions, because gas would collect in the air passage. This slide, therefore, serves to overcome this tendency of the gas to catch up on the air by reason of different pressures.

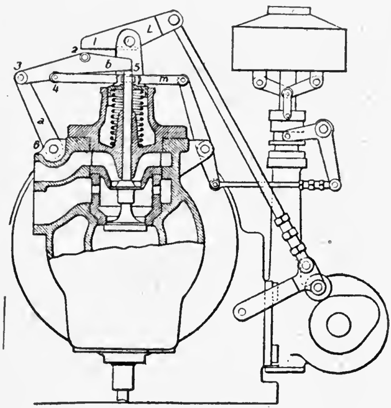

Fig. 141

As the atmospheric air has no tendency to flow except during suction, the air damper valve might be done away with and in many engines actually does not exist.

Similarly, the slide attached to the valve stem to prevent the gas flowing over to the air passage is often omitted, but other devices are substituted in its place. In Fig. 141 is shown a mixing valve of a different sort, forming part of the main inlet valve, a second disk attached to the main valve-stem opening and closing the gas passage. These latter mixing valves are all mechanically opened and closed, whether attached to the main valve-stems or independent, whereas some of the good mixing valves of the independent class are automatic. One of this kind, shown in Fig. 142, is a sort of check-valve arrangement. Any reduction of pressure in the upper chamber *m* and *T* lifts the peculiar shaped check-valve which has two seats *a* and *g*, so that gas passes out into the reduced pressure mixing chamber from the gas-pipe through port *g*, at the same time that air passes up through slot *a*, the two streams crossing and so mixing. Later, by passing upward through other slots *m*, the air and gas are further mixed or stirred. In the mixture chamber there is a damper control valve *T* to fix the amount of mixture that may reach the engine. The relative advantages of all these ways of making mixtures and proportioning them, together with perhaps hundreds of other different ones in use, are, of course, beyond the province of such lectures as this. The examples shown will serve as an indication of the guiding principles used to carry out the functions of mixing and proportioning, which are of prime importance. It is a fact that the success of gas-engines, especially large ones, depends very largely upon the perfection with which the details of these devices are worked out.

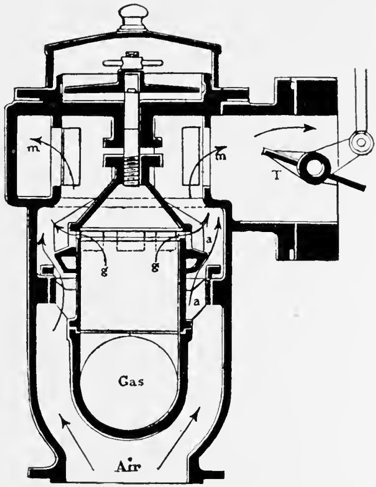

Fig. 142

When the proper sort of mixture is made by means such as have been examined, the next thing necessary is to adjust the quantity of mixture that the engine may receive. From the last figure it appeared that there was a damper valve between the mixing valve and the main inlet valve. This is one of the simplest and most effective means of controlling the quantity of mixture. The main inlet valve is opened the same amount every time by the mechanism, but the engine can get no mixture if this damper is shut; if it is opened wide, a full charge will be taken. The amount of this damper opening is, therefore, a measure of the quantity of mixture the engine can get, while the mixing valve makes automatically as much as is required, and of the proper kind. It is the function of the governor of the engine to fix the position of this damper. At light loads the speed rises and certain free weights of the governor move, fly out, and actuate the damper through rods, moving it to the closed position. At heavy loads the speed reduction moves it to the open position and such sensitiveness can be secured as is surprising to a stranger. This device is an example of the principle of controlling the quantity of mixture by a throttle valve, independent of both the mixing valve and of the main inlet valve. There are other ways of doing the same thing, and many of them, and one or two examples of typical methods will be illustrated.

Instead of having a mixture control valve, or throttle valve, between the mixing valve and the main inlet valve, and all three independent, the throttle effect can be secured at the main inlet valve by varying the lift of that valve, at light loads letting it open just a little, and at full loads permitting full movement, as controlled by the governor. Such a device is shown in Fig. 143. The cam shaft is shown at the side carrying a cam which strikes the roller, and through a guided push rod causes the lever *L* to move upward. The other end of the lever *L* at the left is fixed to the valve-stem by a pin shown at *l*, and on the top this lever is curved to an arc of a circle, having its center at 2. Along this curved portion may be swung the shaded point attached to the bell-crank. This point is the fulcrum of the lever *L*. When the point of the fulcrum is close to the valve-stem, that is to say, at the left, the constant lift of the outer end of the cam will move the valve but little, whereas if the lever point is at the outer end of *L*, the valve will move a good deal. The governor shown above the cam fixes the position of this movable fulcrum so that at high speeds it is in one position, and at lower speeds in another position, thus varying the quantity of the mixture by varying the extent of the main valve lift through which all mixture must pass. This is known as the variable lift inlet valve type of mixture control, independent of the mixing valve. Another type controls the quantity of mixture at the mixing valve itself, independent of the main valve and with no separate throttle. Such a device is shown in Fig. 144. Here the governor

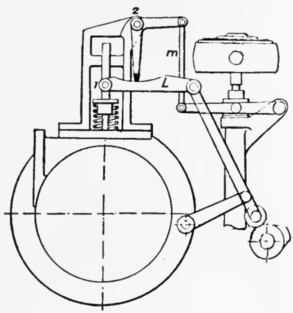

FIG. 143

moves a cylindrical sleeve up and down, thus varying the opening of the slots in the sleeve *A*, which communicate with the air and gas passages *C* and *D*. This up-and-down sleeve movement will close both air and gas passages at the same time and in proportion, independent of the main inlet valve. It is the function of the governor to fix the vertical position of this sleeve, which will, therefore, have a position for each speed and remain there until the speed changes.

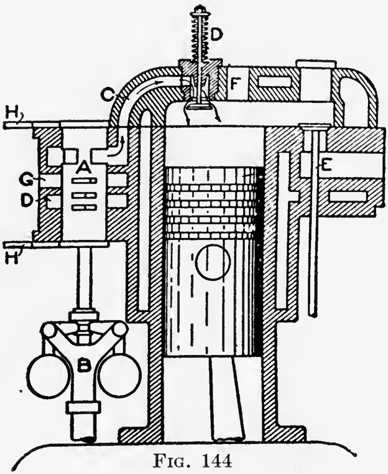

Fig. 144

There are several hundred different systems for controlling the quantity of mixture admitted to the cylinder while maintaining its quality constant, and others for varying the quality intentionally, with all conceivable combinations of these functions of making mixtures and admitting them to the main cylinder; but from what has been said the nature of the problem should be clear.

In all modern engines the mixture that is formed, admitted, and compressed is ignited by electric sparks except in a few types of oil engines that will be discussed later. These electric sparking arrangements are of two general classes, but all have the same effect. In the class known as the make-and-break spark two metal parts are brought together within the cylinder so that an electric current, generated either by batteries or little dynamos outside, may flow through the point of contact. When the point of contact is broken, the electric current, especially if it is assisted by a coil, the details of which need not be described here, will not immediately cease flowing, but will have a tendency to jump the gap, forming a little stream of flame, which will, of course, break off when the gap gets wide enough. The best practical illustration of this action is the ordinary arc light used in the streets for illumination. Here the two parts are carbon pencils which originally rest together in contact, but when the current flows through them they are drawn apart by means of mechanism in the body of the lamp and maintained at a certain distance so that the electric flame or arc can continue to pass. In the gas-engine igniter of the make-and-break type, metal parts are used in place of these carbons and are brought together and sprung apart at the proper point of the stroke by suitable mechanisms. This short electric flame or arc ignites the mixture in contact, after which its own property of self-propagation will suffice to inflame the whole mass. In the other system of ignition two fixed points, both of metal, are used, projecting into the cylinder. Current of very high electrical pressure or voltage is led to these two fixed points, the ends of which are separated only about $\frac{1}{16}$ inch. When the electrical pressure is high enough, the current will jump the intervening space and thus make a sudden flash. This is known as the jump spark system and a common illustration of jump sparks is lightning. The jump spark is really nothing more than a little flash of lightning, differing from it only in the fact that its path and the time when it is to pass are also controlled mechanically.

This review of the principal processes underlying the obtaining of power by the explosion of gaseous fuel and air mixtures has been based more on the ideas involved than on the mechanism because, as was the case with the steam-power system, the mechanism may have great variety of form and detail and still be essentially the same in what it is able to do. By these processes, embodying any one of the standard forms of mechanism, it appears that we are able to transform the heat of combustion almost instantly into useful work, or at least part of it. Both combustion and work generation take place within the same cylinder chamber, and the second immediately follows the first. There is no intermediate substance introduced, like water and steam as in the earlier systems, involving losses of heat in making the steam and controlling its flow. Such losses as occur take place right in the same chamber where everything else happens. By means of this direct procedure, and it is to the method that attention should be directed, it is possible to transform more of the heat of combustion into work than by using steam between the fire and actual working chamber, so that gas-engines are essentially capable of higher thermal efficiency than steam plants. Cases are on record in which there was generated into work over 30 per cent of the heat of the fuel, about twice what our best steam-engines are capable of doing, and it is a common every-day practice to secure efficiencies of from 25 to 30 per cent. Of course, it must be remembered that the gas-engine cannot do this unless the fuel is in the proper gaseous or equivalent form, and coal is not in that form naturally. When coal is transformed from its solid, natural condition to the gaseous form, a perfectly feasible process, there will be involved a loss, so that when gas-engines are to operate on coal fuel something must be subtracted from these efficiencies, but not a great deal. Another very remarkable fact concerning the efficiencies of these engines, which must not be forgotten, is that the little engine of 25 h. p. has almost as high an efficiency as the large ones of 2500 h. p. This is another striking contrast to steam-engine performance, in which to get a high efficiency the engine must be large. It has already been pointed out that the average horse-powers of engines used in manufacturing operations is small, less than 100. In such sizes these gas-engines are ever so much more efficient than steam-engines, being built to convert from two to four times as much of the heat of the fuel into work as the corresponding steam-engine can do. It, therefore, seems reasonable to expect that, as the use of these gas-engines becomes wider as they become better known, there will result for the general average of conditions throughout the country a very material reduction in fuel consumption for the same power, or a large extension of the total power for no increase in fuel consumption. They, therefore, are likely to be found the greatest fuel conservation means that the country has yet seen. Their construction and extended use may be expected to improve with time, and their reliability of operation and popularity with power users will depend upon the perfection with which their details are worked out structurally. The structural developments which have led to the modern gas-engines are scarcely 10 or 15 years old. Much more may we expect of the system when it has been in use for 160 years, which is the case with the steam-engine. No one familiar with the subject would dare to predict the possibilities, but that great progress will be made is absolutely certain.

VI

ADAPTATION OF SOLID AND LIQUID FUELS FOR THE USE OF INTERNAL COMBUSTION ENGINES

All early gas engines were operated on illuminating gas used as a fuel, so that their use was confined to cities where such gas was available; and the sizes that could be economically so operated were limited also, because this kind of fuel is very expensive. To illustrate this latter point, assume that illuminating gas is sold at $1 per 1000 cubic feet, each cubic foot yielding on combustion 600 heat units. Under these conditions the purchaser receives for his dollar 600,000 heat units. Compare this now with bituminous coal at $3 per ton of 2000 pounds, each pound yielding about 15,000 heat units, thus giving to the purchaser 30,000,000 heat units for $3 or 10,000,000 for one dollar. Under these conditions it appears that such gas fuel is nearly 17 times as costly as the coal, so that power users cannot afford to use such gas in competition with this coal unless there is a corresponding difference in the amount of heat that can be converted into useful work in favor of the gas. In other words, unless a gas-engine using this fuel is capable of transforming into work 17 times as much of the heat it gets in the gas form as a steam power system can convert from the heat in coal form, there would be no advantage in the use of gas-engines. Enormous as this difference may seem, fully this much exists when the units are very small, a few horse-power, for example, so that in installations requiring only a few horse-power it is found to be more economical to use a small gas-engine even with the expensive illuminating gas fuel than to use the same size of steam-engine with the cheaper fuel. This situation is helped by the lower first cost of a small gas-engine compared with the same capacity of steam-engine and boiler together. When, however, the size of the unit increases to several hundred horse-power the situation is quite different. In these sizes illuminating gas as fuel can never compete with coal used directly.

If other and cheaper sources of gas supply, or means of adapting coal and oil fuels for the use of gas-engines, had not been discovered, the gas system of power generation, in spite of its inherently higher possible efficiency, could never have competed with the steam system in the larger sizes. In the development of the gas-engine mechanism up to the time when it had been demonstrated that it was a commercial machine, two sources of cheaper gas appeared. The first was the natural gas which issues from the earth, but in only a few localities, the most notable of which are the middle Central States, Pennsylvania, Ohio, Illinois, Indiana, and West Virginia. This fuel is ideal and in some places can be produced and sold as low as 5 cents per 1000 cubic feet. As this gas yields about 1000 heat-units per cubic foot, this price is equivalent to 5 cents per 1,000,000 heat-units, or 20,000,000 heat-units for $1, a decidedly cheap fuel for use in gas-engines, when it is considered that these engines can convert into useful work 25 or 30 per cent of the heat in the gas. One other source of cheap gas supply is the blast-furnace in which iron ore is converted into pig-iron. To these furnaces, which are almost the same in general character as tall chimneys, alternate layers of coke, iron ore, and limestone, in measured quantities, are fed at the top; heated air is blown into the bottom and the whole interior becomes a white-hot mass. The heat causes the limestone to combine with the rock which binds the iron in the ore form, thus setting free metallic iron, all through the influence of the heat of combustion of the coke. From the top of the furnace there is discharged a rather weak but combustible and useful gas, which is mainly nitrogen from the air, about 70 per cent. The other 30 per cent is principally carbon monoxide gas, which is the result of combining one particle of carbon with one particle of oxygen, and which is combustible when one particle of the gas takes up another particle of oxygen. This combustible gas, always consumed in stoves, is used to heat the air-blast, and under boilers to make steam, the steam being used to run blowing engines to supply the air which the furnace requires. This gas-generated steam is also used to supply power for rolling the iron into bars, operating hoists, pumping water for electric light, and a variety of other purposes. When the gas-engine appeared, this same gas was burnt directly in cylinders, yielding twice as much power as before, making available for sale an amount of power equal to what the small plant itself used. Each blast-furnace, more especially in Germany, where questions of economy receive most attention, became then a source of power for the community, much the same as a waterfall.

Because the gas-engine is able to convert so much more of the heat of the blast-furnace gas into work than the steam-engine it displaced, the work of the plant was done as before, and about an equal amount of power was left over to be sold to neighboring factories, to operate street railways, and to light neighboring towns.

The really important developments, however, were not possible without the adaptation of the more common natural fuels, oil and coal, and this adaptation has now been carried to fair success, though much improvement is yet to be accomplished. To understand the apparatus by which coal and oil are rendered available for gas-engines, requires, first, an understanding of the peculiarities of the fuels themselves. Perhaps the earliest attempts to get a combustible gas from coal involved the use of roasting processes, of which there are two important classes: one in which the gas that is driven off in baking is wanted, and the other in which the residue or coke is wanted; in either case the other product is considered a waste or by-product. In the making of coke from bituminous coal the standard method for a great many years has been to put a layer of crushed material in the bottom of a circular chamber, having an arched roof and more or less resembling a beehive, as shown in Fig. 145, and hence called a beehive oven. This coal is ignited from the top and side, and air is allowed to enter the first door slowly. The heat, driving off the gas which the coal yields by the roasting process, is derived from slowly burning the former in the upper part of the domelike chamber until the whole bed has been equally roasted. In these beehive ovens the flame and burnt gases escape from the top through a hole. The coke which is left, and which weighs about 50 or 60 per cent of the original coal, is drawn out and used in blast-furnaces where coke is needed; but in the formation of the coke a peculiar thing happens. At a certain stage of the heating the whole mass may be said to be practically melted, each small particle of the original coal entirely losing its identity and merging with the rest, much the same as broken molasses candy will melt together in hot weather.

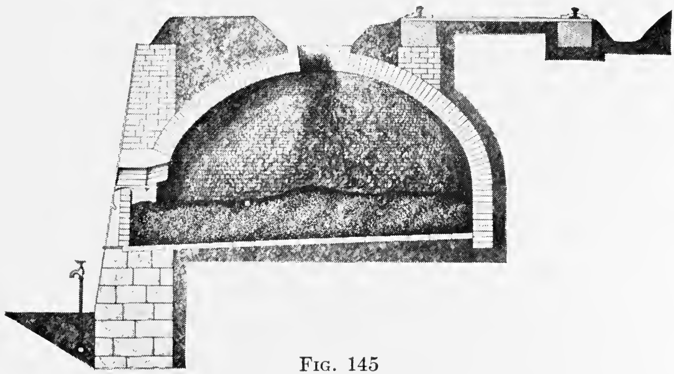

Fig. 145

From the molten mass gas continuously escaping punctures it full of holes, and in time, the gas being all driven off, the rest of the mass solidifies into a single piece of hard, porous coke. It would be a single piece if the mass did not shrink in the process, but it does shrink, producing a series of fissures or cracks, so that the coke consists of large pieces, sometimes as large as a man's body, but generally smaller, bearing no resemblance whatever to the original shape or size of the particles of coal from which it was made. This beehive oven method of roasting coal produces gas which is allowed to go to waste, the heat of which is partly used to maintain the temperature for the rest of the process. Thus, gas is the waste material and coke the desired product.

An almost exactly similar process of roasting is carried out in the manufacture of coal-gas, one kind of illuminating gas, in which gas is the desired product

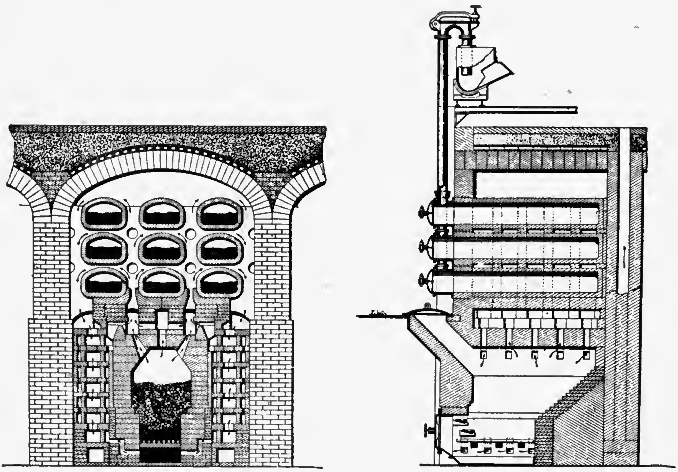

Fig. 146

and the coke the waste product. In this system coal is fed to earthenware chambers open at one end and closed at the other, called retorts, shown in Fig. 146; a number of them, in this case nine, being placed side by side in the same brick setting and a fire maintained below to heat them from the outside. The heat from the fire below roasts the coal in the retorts, driving off the gas, which is caught, and after purification is finally pumped through pipes in the streets of cities for illumination, for gas-stoves or small gas-engines. After the roasting has proceeded for a time sufficient to drive off all the gas, the coke that is left is drawn out and sold, a large part going to bakers for their ovens.

In these coal-roasting processes there is driven off from the coke what we are pleased to call gas. It is, however, a most complex mixture of gases and vaporized liquids, consisting of various compounds of carbon, hydrogen, oxygen, and nitrogen, with occasionally some sulphur. As carbon and hydrogen are the main fuel constituents, it is very common to regard all these distillation substances as hydrocarbons, and these hydrocarbons are all in the gaseous form as driven off because they are very hot at that time. When they are cooled, however, it is discovered that some of them will condense into viscous or thick liquids of bad smell and brownish black in color. These are called by the general name of gas-tar, coal-tar, or just "tar," and it is this tar which is responsible for the melting previously referred to.

The adaptation of coal for gas-engine purposes should leave no by-products. All the coal should be converted into gas, so that mere roasting is not sufficient, for even though it yields a gas there is also left over the coke, and means must be found for gasifying this coke, which means will also be found to serve for the gasifying of anthracite coals, which themselves yield little or no gas on roasting.

The process by which coke or anthracite coal may be completely gasified involves no such simple treatment as roasting, but chemical combination of the carbon, which is the main constituent of both these fuels, with oxygen of the air, much the same in kind as takes place in the blast-furnace itself in the making of iron from its ore. When air is supplied to a fire of coke, charcoal, or anthracite coal, it is believed that one particle of carbon will combine with two particles of oxygen of the air, the nitrogen being carried along as inactive and neutral, so that the resulting gas, called carbon dioxide, or CO_2, and which is incombustible, is called the product of complete combustion of carbon and oxygen. If this particle of carbon dioxide, which is one particle of carbon and two particles of oxygen combined, be passed through more hot coke or carbon, then a further reaction is believed to take place. Another particle of carbon will be taken up, making two particles of carbon monoxide, which gas consists of one particle of carbon combined with one particle of oxygen, and which is combustible because it is capable of taking another particle of oxygen if it is available. To carry out this double chemical reaction, air is supplied to a very thick bed of fuel, from 3 to 8 feet thick, and there is produced a combustible gas. All the coke or fixed carbon is consumed or converted into combustible carbon monoxide gas. This is the basal principle for the gasifying of solid carbon. It, together with the roasting process, constitutes the means for adapting coal fuel to gas-engine service, or the means, in other words, of changing any kind of coal completely into combustible gas with no residue and no by-products. The apparatus in which these double processes are carried out is called a gas producer, and by the invention of gas producers solid fuels became available for gas-engines. However, differences in fuels and differences in the desired kind of gas have led to very great differences in the forms of gas producers. A simple gas producer is shown in Fig. 147. It is a chimney-like structure, not very high compared with chimneys, containing a grate at the bottom through which air is blown, ashes on the grate, coal fed from the top, and the various steps in the process of gasification indicated by lines drawn across, making zones in the fire. In the first zone above the ashes the temperature is highest, this being the place where carbon is completely burned into carbon dioxide. The next zone above being less hot, the carbon dioxide is here reduced to carbon monoxide; the top zone is the roasting or distillation zone, through which all the gases pass, and where the gases made in the lower zones mix with those distilled from fresh coal in the top, the whole gas mixture passing over through pipes preparatory to being supplied to engines. Just as hydrogen in burning combines with oxygen to form water vapor, so will water vapor when brought into heated chambers decompose into hydrogen and oxygen; and, similarly, when brought

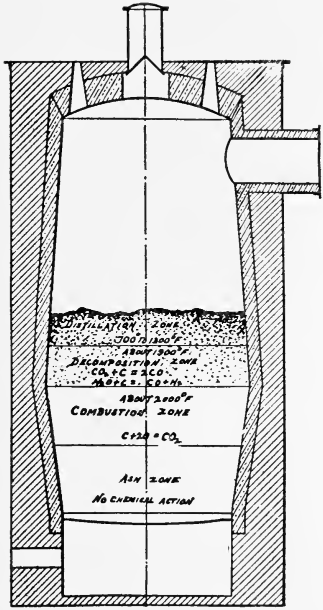

Fig. 147

into contact with hot carbon the oxygen that comes from the decomposition of the water combines with the carbon, leaving the hydrogen free. If water vapor be supplied with the air, the gas produced in such a producer will, therefore, consist first of the hydrocarbon products of distillation or roasting; second, of carbon monoxide, the result of combination of fixed carbon with oxygen; third, of hydrogen, the result of decomposition of water vapor or moisture carried in the air, or of steam supplied with the air; fourth, of nitrogen carried in with the oxygen; fifth, of various other things in quite small quantities, such as some free oxygen that has escaped, some carbon dioxide that failed to reduce, or some sulphurous gases.

If such a producer is supplied with air by a fan or blower, there will be a tendency for the lower part to get very hot, hot enough to melt or flux the ash and make clinker, stopping up the air supply. The most effective way known of meeting this trouble is to supply steam with the air. As hydrogen and oxygen in combining liberate heat, so will the water vapor on decomposition absorb heat, and steam supplied to the fire will in decomposing in the hot part cool it sufficiently to prevent the formation of clinker. Continuous operation with coals that tend to clinker demands means for clinker prevention, and this led to the application of a steam-jet blower, such as is shown in Fig. 148,

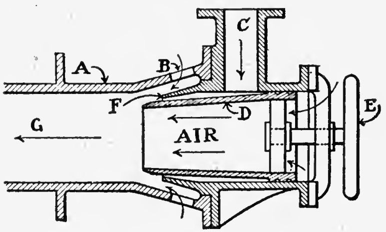

Fig. 148

in which the steam-jet drives along the air. This blower not only supplies the steam necessary to prevent clinker, but the air for combustion with the coal. All the earlier producers used to drive gas-engines were operated with these steam-jet blowers. One of these producers, of American design, very largely used, is shown in Fig. 149, in which, however, the blower is omitted. It would be attached to the blast-pipe at the left. The end of the blast-pipe has a cap which serves to throw the air and steam mixture more or less uniformly across the whole bed and to keep ashes out of the pipe. On the grates, which are inclosed in a tight chamber to prevent the escape of the blast, a considerable amount of ash is left at all times to avoid burning them. A crank outside enables the shaking down of ash to maintain a proper level without opening the ash chamber, but once a day this is opened to remove collected ash. Another style of the same producer without any grates is shown in Fig. 150. Here the ashes simply rest in a water trough at the bottom, and the edge of the casing dips into the water far enough to prevent escape of air from the interior. Ashes may be removed from this water-seal bottom by raking

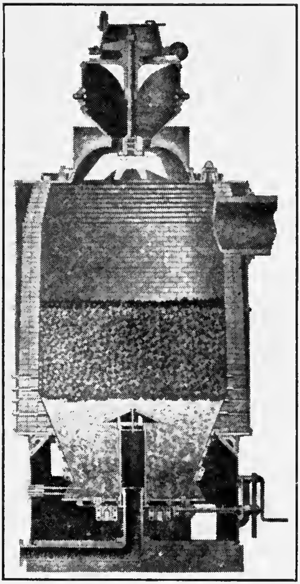

Fig. 149

under the water at any time. Producers such as have just been shown, operated with the draft upward and under pressure, are called up-draft pressure producers. These had not been in use for many years in Germany, where they had their most vigorous development, before it was realized that the suction stroke of the engine in drawing in its charge of air and gas might be made to also draw the air and steam through the coal-bed of the producer. This seemed especially desirable because the steam-jet blower type of producer required the addition of a steam-boiler to produce the high-pressure steam required, and, moreover, considerable variation in the proportion of air to steam, with consequent variable quality of gas, could not be avoided. This boiler, if the blast were to be produced by the engine suction alone, would not be necessary, nor would a separate engine-driven blower be necessary as a substitute for the jet blower. The new combination became known as the suction gas producer, one style of which is shown in Fig. 151 in section and externally in Fig. 152. The gas on leaving the producer proper is shown at the left passing through a chamber fitted

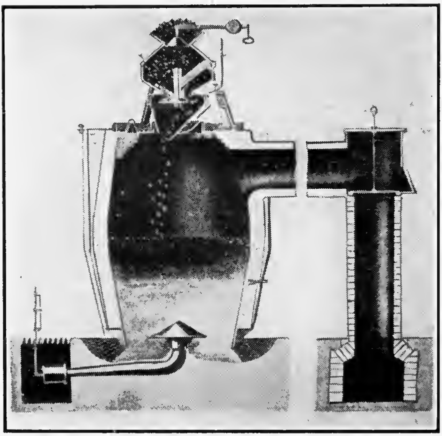

Fig. 150

with tubes which are surrounded by water. The gases leaving the producer warm this water, producing water

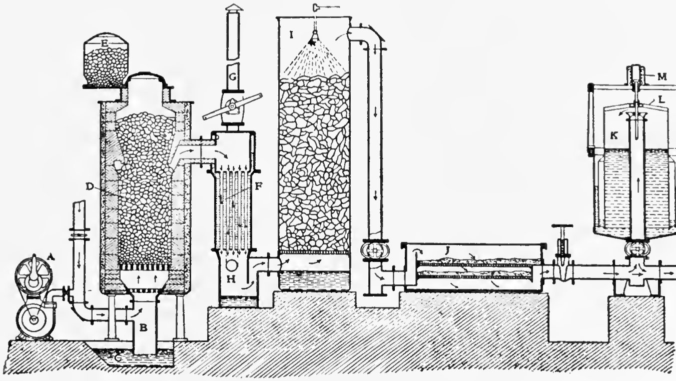

FIG. 151

vapor or steam, which is drawn into the bottom of the producer with the air through a connection not shown. The hot gases from the producer make all the steam

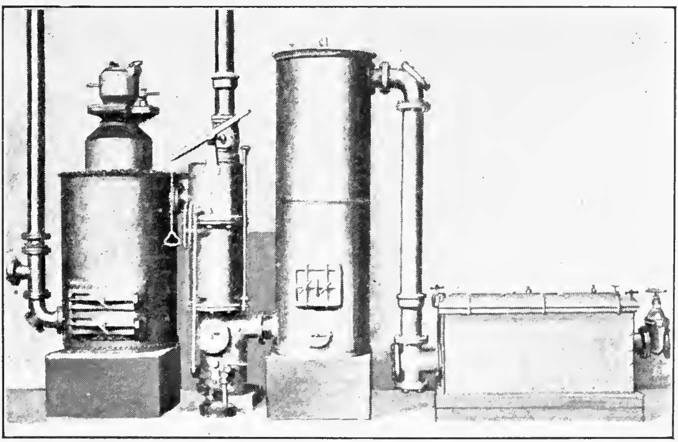

FIG. 152

necessary to prevent clinkering and without any high-pressure boiler. After leaving this vaporizer the hot gases pass through a tower chamber full of coke or any other similar porous substance kept continuously wet by a water spray at the top. This serves the double purpose of cooling the gas and removing from it most of its coarser particles of dust carried from the fire. Finer particles of dust, together with particles of tar which may have come from the roasting of the green

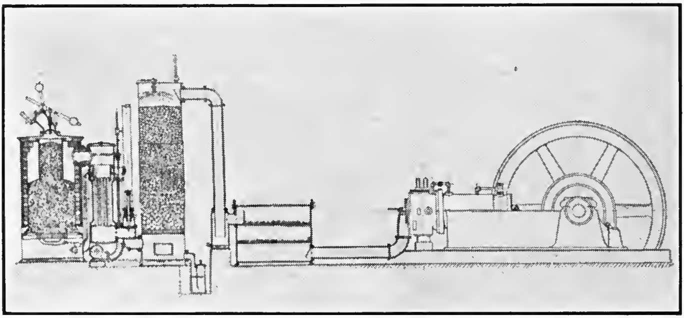

FIG. 153

coal, are removed later by passing the gas through layers of sawdust and wood shavings in a sort of tar extractor or purifier. From this last cleanser the gas passes directly to the engine, the entire flow through the apparatus being caused by the suction of the engine itself. A slightly different design of the same type of producer is shown, together with the engine, in Fig. 153. With a view to simplification, some of these suction producers are arranged with the vaporizer around the top of the producer chamber itself, thus making a separate vaporizer chamber unnecessary.

Such a producer as this is shown in Fig. 154 without any of the additional parts. The air is drawn over the top of the warm water before entering the ash-pit, and a float-valve chamber is provided to keep the water-level constant. A small blower is provided at the bottom to supply the air. With a view to adjusting the quantity of steam to the air a little more positively, special devices have been designed, in which water is fed to a pipe dipping into the hot discharge gases so that it is warmed almost to the boiling point. It then drops into a funnel that guides it to a narrow cast-iron trough running around the producer top casting and which is hot enough to vaporize all such water before it gets to the end. Air drawn into a hot gas heater and warmed by ribs passes over to the vaporizer casting, so that the steam there formed mixes with it. By this means the mixture proportions of air to steam can be controlled at will. If nothing but air be supplied to these producers, there will be no hydrogen in the gas. If nothing but steam be supplied, and, of course, this

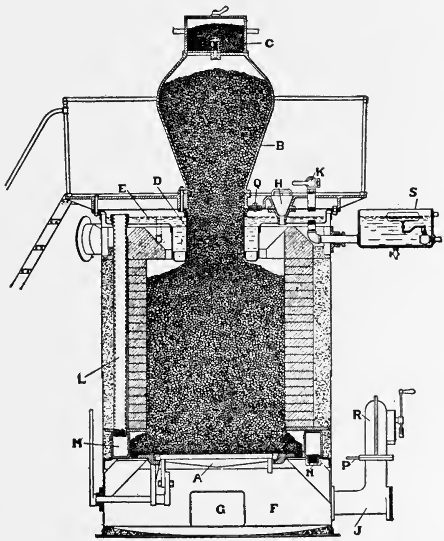

FIG. 154

is only possible for a short time, as it will put out a fire if continued too long, there will be a great deal of hydrogen. Therefore, as the quality of the gas varies quite rapidly with the amount of hydrogen it contains, the quality will in turn vary every time the proportion of steam to air supplied is varied. Steam-jet blowers are unable to maintain this proportion correctly. Separate vaporizers on suction producers, or other contained vaporizers on the producer bed, are better, but still not quite satisfactory, so there has been made a series of attempts to maintain this proportion constant automatically by mechanical means. These are so numerous and so different that it would be quite impossible to examine them, but it should be noted that this is a very important matter and one now receiving a good deal of attention. Another matter receiving attention at this time is the means of keeping the bed compact, for if the bed should not be compact and holes should form in it, the chemical processes that should be carried out will not take place, and there will result a considerable loss of efficiency and bad or unsteady gas will be produced.

All of these producers shown work quite well with coke or anthracite coal in spite of tendencies to make variable gas, if skilfully operated, but most of them work quite badly with bituminous coal because of the coking and tar tendencies. Bituminous coal may or may not cake, but always contains much tar. This tar, if it lodges on the engine valves or moving parts, will make them stick; if it gets into the interior of the cylinder, it will make deposits of carbon which are very bad on the action of the engine. The tar must, therefore, be eliminated or means be provided for preventing it reaching the engine. Naturally, the first idea to be applied was that of removal after formation. Tar was allowed to form in the producer and extractors were made to get it out of the gas. The means first employed were very similar to those adopted for removing the dust from gas, which means are most elaborately carried out and applied to the gas from blast furnaces, as it is most dirty.

There are a great many processes and apparatus available for removing dirt more or less completely, most of them quite simple in idea. One of the most common is the spray tower already referred to, n which the gas enters the bottom, passing upward through wet coke, over which water is sprayed from the top and runs downward to keep the coke wet. The primary object of this sort of cleaning tower is to catch dust, and this it does pretty well. It also, however, cools the gas and so causes a certain amount of tar vapor to condense in small, liquid tar drops which the coke is ineffective in removing. Other forms of tower involve all sorts of systems for extending to the gas a great number of square feet of wet surface by allowing the water to fall over piles of wood or through series of metal bars or over plates. All cleaners of this class may be called static cleaners of the contact sort. By narrowing the spaces through which the gas must pass, especially when the substance is absorbent, there results the filter type of cleaner. In this the gas is forced through spaces between finely divided material such as sawdust, cheese-cloth, excelsior, or wood-chips. Such a cleaner is shown in Fig. 155, in which the fibrous or filter material rests on pans, arranged for convenient removal when dirty. As tar is greasy and most of the static cleaners and filters get wet, they soon cease to absorb, as the water repels the oily tar. A third class of cleaner, which has proved more effective for tarry substances, but which is also effective for dust, is mechanical in action. Rotating blades dipping into water throw a continuous spray across the chamber through which the gas must pass, at the same time exerting a churning action to concentrate the tar drops, much the same as a butter churn collects particles of butter fat. Such a cleaner is shown in Fig. 156.

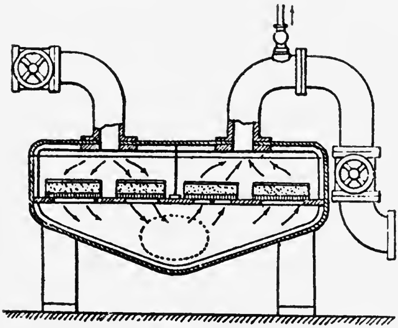

Fig. 155

The ribs on the drum *D* catch up water in the bottom of the casing and throw it out by centrifugal force, the gas meanwhile passing through the veils of mist at right angles and suffering a beating by the ribs and the heavy drops of water. These few examples will serve to show the typical means employed to solve this most important part of the problem of the preparation

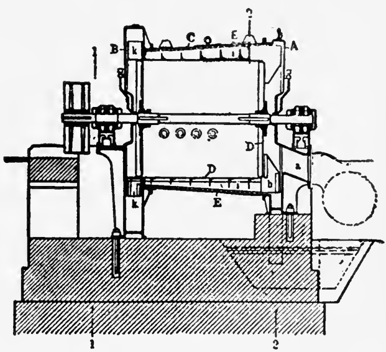

Fig. 156

of gas, made from bituminous coal and containing tar, for engine use. Tar extractors have been based on practically every plan ever proposed for dust removal; the passing of the gases over wet surfaces, which did not work very well because tar is greasy and slips past; the filtering method likewise; and finally all sorts of elaborate churns, and these churns are now the main dependence.

Even if separation is complete, an additional difficulty in operation is encountered in bituminous producers, in which the volatile gases are allowed to mix with the gasified coke, as is done in all these systems that depend on tar removal later, and this is the fluctuation in the quality of the gas. The volatile gases driven off in roasting have about six times the heating power of the gasified coke, so that any change in the proportion of these gases makes a considerable change in the quality of the final gas mixture.

Belief is growing at the present time that it is not sufficient merely to attach to bituminous producers tar extractors, nor advisable even though it were sufficient, as the primary trouble is in the fire itself, and means are being sought for changing conditions in the fire so that the tar will not be formed at all, or if formed, be destroyed. Various plans have been tried and others are being proposed every day; some of them are in the experimental stage, others no more than proposals for overcoming the difficulties of caking, tar formation, and the fluctuating amounts of volatiles from the rich, bituminous coals. One principle for the destruction of the tar involves the reversal of the draft, so that coal fed to the top would be supplied with air at the same point which would pass downward through the bed instead of upward. The passage of the volatiles of the coal downward through the bed is expected to decompose the tarry hydrocarbons, breaking them up into permanent gases and fixed carbon soot that is more easily filtered out than greasy tar, and this plan is fairly effective. One example of this system is illustrated in section in Fig. 157, in which there are two gas generators used alternately. Air is drawn through the bed downward by a suction

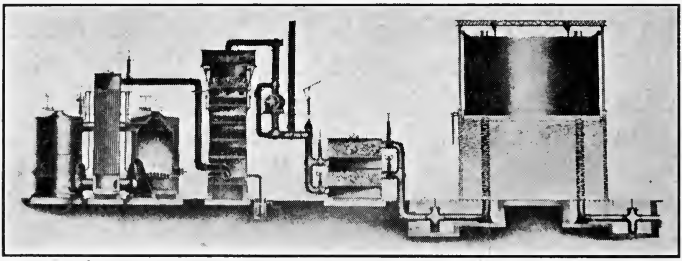

Fig. 157

blower shown about the center of the picture. The hot gases first pass through a tubed steam-boiler and then are cooled in a wet tower. After cooling, the gas passes through a blower to a soot filter and finally to a gas-holder. This operation makes the bed very hot; when it gets as hot as is permissible the air is shut off and switched to the other producer, and steam from the boiler is blown through the first, making a gas rich in hydrogen, until the bed has cooled. The alternately made rich and poor gases are mixed to get a uniform gas for the engine.

In this system practically all tar is destroyed, but soot is found instead. A producer, based on a combination of up-and-down draft and continuously operating, is shown in Fig. 158, together with the cleaner and suction blower. Coal fed at the top passes downward and some air with it, the volatiles perhaps partly decomposing. Air also passes upward from the water-sealed bottom and the gases formed in both the upper

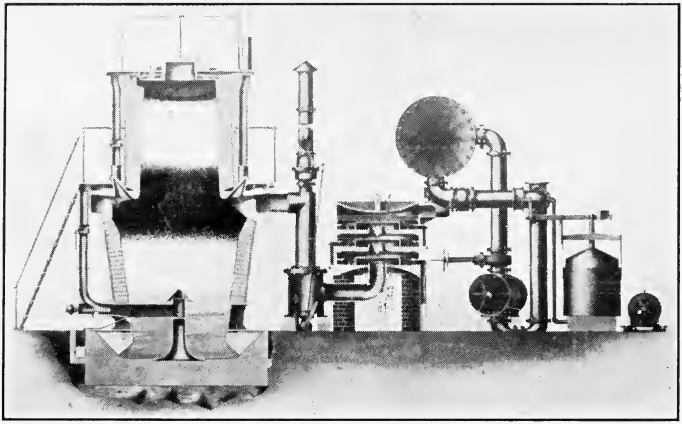

Fig. 158

and lower chambers mix and pass out at the middle. Around this central zone is placed a ring trough containing water, over which all entering air passes and takes up steam enough to keep the bed cool.

By this plan there might be expected both tar and soot in proportion, depending on the adjustment of top and bottom blast and bed temperature, such volatiles as are only slightly heated yielding tar, the rest that are highly heated yielding soot. Should the coal cake much while roasting, both these producers would require much poking to prevent the stoppage of air. A still more radical plan, toward which the latest thought seems to be directed, involves the elimination, not only of all the tar and soot, but also all the rich volatiles of the coal, making a larger amount of weak gas but very constant in quality. The basal idea underlying the accomplishment of this object is well illustrated by a combination of the beehive oven and the blast furnace. The beehive oven roasts the coal, burns up the volatile, and makes coke; the blast furnace completely gasifies this coke and is capable also of causing a combustion between its coke and the waste gases of the beehive. If, then, the top of the beehive oven be connected to a blast-furnace air supply, the products of combustion of the volatile from the oven can be made to combine with the coke of the furnace and the supply of coke will likewise be maintained by the oven. In Fig. 159 one form of producer embodying this idea is shown. There are two parts to the fuel bed, the first or upper part resting on a grate *f*, through which the air can pass, burning some of the coal just as it burns under a boiler,

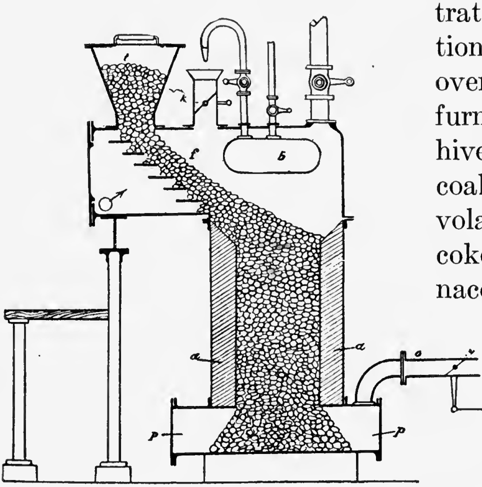

FIG. 159

but roasting out the volatiles. As the coal passes down and across the grate, all the tarry substances may be driven off and in burning fill the upper chamber with a long flame. At the bottom of this grate most of the volatiles will have roasted out and burned as in the beehive oven, leaving coke for the lower chamber. Through this main coke bed the burnt products of the volatiles will pass and be reduced to combustible carbon monoxide gas and hydrogen by chemical combination with the coke. No producer of this class is yet in use, and this one is shown merely to illustrate another idea for meeting the difficulties of securing a suitable gas for engines from bituminous coal. That there are real difficulties in the complete gasification of bituminous coals and other special grades of coal, such as peat, was not originally realized; but now, as the problem is more completely understood, great progress is being made, so that before long it will be possible to gasify every grade of fuel as well as can now be done with anthracite and coke. When this happens, the gas-power plant will become a universal competitor of the steam-power plant so far as the fuel supply is concerned, and in competition with steam will make it possible to secure more power from coal than we now get. In plants of large size 20 per cent excess efficiency over steam may now be secured, while in small ones of about 100 h. p., the steam plant will burn four or five times as much coal per horse-power hour as the gas plant consisting of producers and gas-engines. This is especially interesting and important when it is remembered that the average power plant is small, — less than 100 h. p. in the manufacturing industries, according to the last census, — so that for the country as a whole, it is of far more importance to improve fuel consumption in small plants than in those great ones familiar to New York, used for the trolley roads and central stations. The gas producer and gas-engine may, therefore, be regarded as important factors in the future of power development and most effective in saving coal in those plants which represent the average power requirements of individual users.

What these small producer gas plants are doing for the average power user with solid fuels, the oil or gasolene engine is doing in even greater degree for other fields that it has made especially its own, and in which it has in some cases absolutely no rivals. Liquid oil fuel as obtained naturally is a mixture of many things, and when heated in retorts or stills will yield those substances in a certain order. Substances like gasolene begin to boil out first, are condensed, and sold under a trade name. As the temperature rises in the retort or boiler, when the gasolene is nearly gone, a heavier substance is obtained called kerosene; after this has all passed over, the residue may be sold as fuel oil, or from it lubricating oil, vaseline, paraffine, or asphalt may be obtained. Thus, a great variety of substances may be obtained from natural oils, differing, so far as their use in engines is concerned, chiefly in the temperature to which they must be heated to vaporize them. In any case overheating will produce the same effects as the heating of the volatiles from coal; it will cause decomposition into other lighter vapors or fixed gases and soot.

Another sort of liquid fuel has recently become available in this country, known as denatured alcohol, and sometimes sold under trade names, such as Pyro. This is made in much the same way as is whisky, by fermentation and distillation of any substances containing starch or sugar, the substances most commonly used being corn and potatoes. This alcohol is very useful for engines, vaporizing more easily than kerosene, but not so easily as gasolene. It is nearly pure alcohol, to which is added, to prevent evasion of the liquor tax, substances like wood alcohol and benzine in small quantities which do not affect its fuel value.

Liquid fuels are adapted to engine use in two characteristic ways, one direct and the other indirect. The indirect method is used with all fuels easily vaporized, while the direct system is used for the heavy oils difficult to vaporize. With the lighter and more volatile fuels a mixture is made external to and independent of the engine by apparatus corresponding to the mixing valve of gas-engines, whereas the heavy oils are most often injected directly into the explosion chamber. The more volatile forms of fuels are treated by devices termed carbureters, which perform a variety of functions at once: they automatically control the feed of the fuel, vaporize it, mix it with the air, and maintain the correct proportions of vapor to air. Thus, in Fig. 160, if gasolene is supplied to a float chamber through the little valve in the top, controlled by the float, the supply will be shut off when the float in the chamber reaches a certain height and opened if the level falls below this point. If, now, there be a nozzle connected with the gasolene from the constant level float chamber, the end of the nozzle just a little above the level in the float chamber, and there be a needle valve in the nozzle to adjust the effective opening, no gasolene will flow out except when the movement of the piston creates a suction at the nozzle, and the amount that will flow under suction will depend on the amount of suction and the needle valve adjustment. To facilitate adjustment of the suction in the nozzle chamber a valve may be provided in the air-pipe, as shown at the right, and the proportions between the gasolene and the air be maintained by the needle valve and the air-valve, just about the same as was done with the mixing valves for the gas-engines previously described. It is found by experience that there is a tendency for the gasolene to increase faster than the air when the

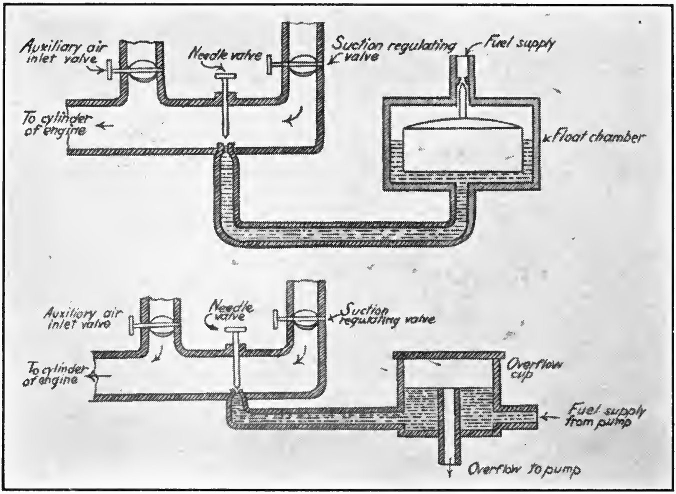

FIG. 160

suction increases, and for that reason an auxiliary air valve is often provided, either hand adjusted or automatic. Such a combination of parts constitutes a carbureter. Vaporizing in it is quite automatic, as the air is hot enough to vaporize the gasolene spray by contact alone, or vaporize enough of it to permit the cylinder to complete the process in compression. In

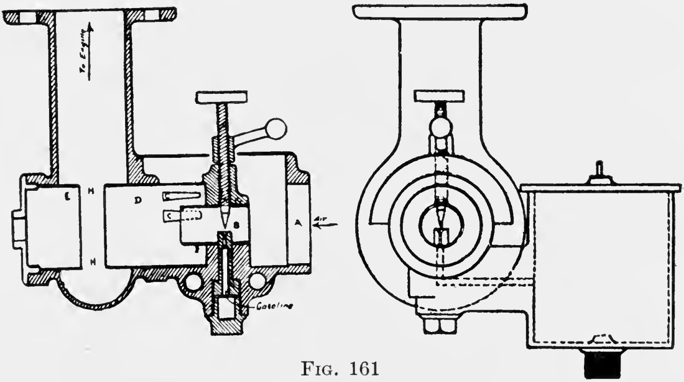

Fig. 161

place of the float chamber there may be a pump-supplied cup with an open overflow, as shown below, to keep the level constant. It would be easy to show perhaps 300 different combinations of mechanisms all constituting carbureters, operating on about the same ideas, but the standard adopted principle is well indicated by this diagram. In Fig. 161 is shown a carbureter from an automobile engine, as an example of one actual form in which the air may enter through two passages, one the spray chamber *B*, and the other ports *C*. These ports constitute the auxiliary air inlet previously mentioned, and the adjustment of proportions is accomplished by the needle valve.

Carbureters operating on these principles and using gasolene fuel, to which they are adapted, made the light-weight self-contained engine a possibility, and were fundamental to the creation of the automobile, motor boat, and the aëroplane. They also supplied means for providing the small power user, like the farmer or operator of the small isolated country shop, with a machine to do the work formerly done by man or horses.

For farm, country residence, and small shop use, there are sold in this country yearly close to 100,000 of these small gasolene engines for application where practically no other source of power would be available. Over 280,000 automobiles are built annually, approximating in value $400,000,000, and giving employment in more than 200 factories to 120,000 workmen, not counting those who are also given employment in running these machines and keeping them in repair after they are sold. The engines of these automobiles aggregate 80,000 h. p., and their value is equal to that of 17,000 consolidation locomotives, which is about three times the yearly demand on the railroads, so that the value of the automobile output is in a fair way to exceed that of all the locomotive construction in this country. The small gasolene engine has produced industrial effects of enormous magnitude, out of all proportion to the machine itself. The little engine that is responsible for such a far-reaching influence is decidedly insignificant in comparison with the big central station and steamship engine. In its own field this little engine has no rivals, and this is especially significant, for it must be remembered that without it hundreds of thousands of men would be doing work by hand, or with horses, in shops and on farms, that is now done by power, and which steam is absolutely incapable of doing, or that work would remain undone. As a matter of fact there is no known system of power capable of doing these same things, except possibly the same engine adapted to use the other liquid fuels such as kerosene, alcohol, or the residue of crude oil distillation.

These other fuels, however, are not so easily adapted to the use of the engine as gasolene because of the greater difficulty of vaporizing them. They must all be provided with a source of heat, which the gasolene does not need. By feeding alcohol or kerosene to such a carbureter as has been described, there will be formed a spray, but before an explosive mixture can be produced and introduced into the cylinder, some heat must be applied. This heat is applied in a variety of ways. Perhaps the simplest to understand is that in which the sprayed air mixture is led through iron chambers on its way to the engine, which chambers are heated first by a lamp and later by the exhaust gases after the engine begins to operate. In other devices the heated part is internal to the engine, and the spray obtained from the carbureter is introduced into the cylinder, there to be heated by contact with hot iron parts which were warmed by the last explosion. When these parts that are to heat the spray and vaporize it are internal, then the engine must be started on gasolene or some equally volatile substance, such perhaps as ether. Another plan involves the use of a heater for the oil alone with a view to converting it into a gas or vapor. According to this plan the oil is fed to hot chambers, by the heat of which some of it is converted into a reasonably fixed gas, while the rest is decomposed into a sooty residue. This fixed gas can then be supplied to the engine as would any other gas. Still another plan, which is confined to the use of distillates, involves the feeding of the fuel to a little boiler where it is vaporized by a lamp or exhaust gases. The vapor thus produced is mixed with air as a gas would be. Of course, all these devices have limitations. When vapor is formed in boilers, means must be adopted to prevent its subsequent condensation and to regulate the amount produced. When the oil is dropped on to hot plates, means must be provided to prevent them getting too hot, otherwise the decomposition and soot formation will be excessive. When the oil is heated by itself, the device is generally termed a separate vaporizer, which must be used in connection with a mixing valve similar to those used on gas engines to adjust the proportions of vapor to air as required by the engine. When, however, a spray is formed and that spray is subsequently heated, then the device is called a carbureting vaporizer or just a carbureter, or sometimes just a vaporizer. Practice in this regard is not yet standardized.

For very heavy oils, such as the residue oils, a different plan has been adopted. The oil is injected directly into the combustion chamber, generally by means of a pump. The chamber into which the oil is thus supplied is hot, the heat being obtained in some cases entirely by compressing air alone, and in other cases entirely by metal parts such as plates and bulbs, and in still others by a combination of these two. One of the most famous heavy oil engines, and one that holds the record for thermal efficiency, approaching almost 40 per cent on test and averaging over 30 per cent in daily use, draws in a charge of air in the usual gas-engine way, compresses it to between 500 and 600 pounds per square inch, which makes the air about red-hot. Into this red-hot air the oil is squirted by a pump in carefully regulated amounts, assisted by a small jet of compressed air from a tank under about 1000 pounds pressure. These engines are expensive to build and somewhat difficult to maintain, so that the other device of using hot plates has been more widely used. One of the most common forms of these hot plates is the bulb form. Such a vaporizer is shown in Fig. 162, forming part of an ordinary four-cycle engine. It is ordinary in all respects except one, for it has in place of the regular head a bulblike chamber connected to the cylinder by a neck. This bulb chamber at its outer end gets red-hot in operation and in the beginning is heated by a lamp placed under it. Heavy oil, even as thick as molasses, when pumped into this chamber will vaporize, but some of it is apt to decompose by over-

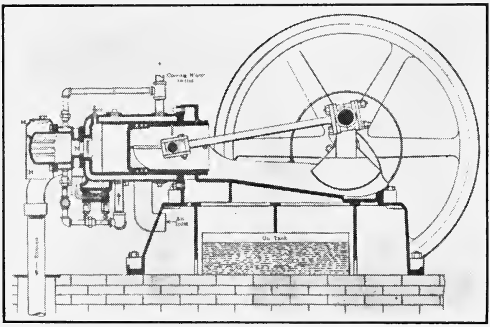

Fig. 162

heating. The compression stroke of the piston will force air into the chamber and in passing the neck at high speed the air will whirl around inside the bulb, mixing with the vapor. Ultimately, as the compression is carried on, the mixed vapor and air become heated enough to cause an automatic or self-ignition, but usually not until the whirling stops, about the end of the compression stroke. Another form of this hot bulb vaporizer, which, of course, is always fed by a pump of variable capacity under governor control, is shown in Fig. 163 in connection with a two-cycle engine. Here a lamp is shown under the hot bulb *B*, which has a lip *L* projecting into the cylinder. The pump *P* discharges oil from the tank downward through a nozzle on to the lip, lip and bulb being red-hot. Compression of the piston forces air over the lip *L* into the bulb *V*, carrying all vapor and unvaporized oil with it. At the end of the compression stroke all the oil is vaporized, and the mixture warmed up enough to be ignited by the red-hot metal, but as some of the oil is sure to be overheated before it burns, a little residue will form. The rest of the operation is substantially the same as that for a two-cycle gas-engine, previously

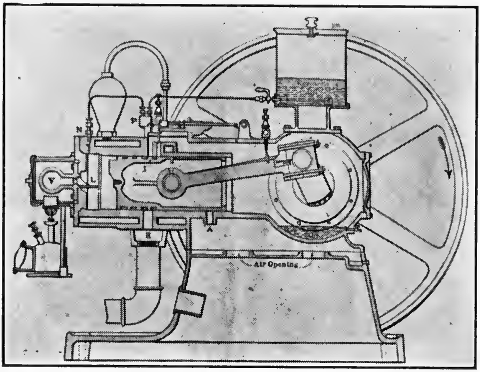

Fig. 163

described. Still another and more recent plan for handling these very heavy oils seeks to avoid entirely a dependence on the vaporizer. It has already been pointed out that a fine spray of oil when uniformly distributed through air will make just as good an explosive mixture as the vapor and air. Of course, the spray must be very fine. In one recent type of oil-engine this is secured by pumping the oil into a little cartridge connecting with the explosion chamber by a small valve. This cartridge is also supplied with highly compressed air, and at the time when an explosion is wanted the connecting valve is opened, air and oil rushing into the explosion chamber together; the expanding air spatters the oil into a very fine mist, blowing it more or less uniformly into a charge of warm compressed air that has been prepared by the engine piston on its compression stroke. By this arrangement an explosion can be obtained instantly, even from oil that is very sticky and thick, the combustion and efficiency being quite as good as with the red-hot air previously noted, and without using over a third of the compression the latter requires. These heavy oil engines, while they have a limited field of application because of the localized and limited supply of oil, do nevertheless fill a most useful gap in the power field, for in many places the fuel oil is far cheaper than coal, and in others, such as California, far from the coal fields, oil is comparatively plentiful. They are more costly than gasolene engines to buy, but their fuel is much cheaper, and as they are not so readily started as the gasolene engine they divide the liquid fuel field.

The gas producer operating on solid fuel, the light oil carbureter, and the heavy oil vaporizer constitute the means by which the natural fuels have been and are being adapted to the use of the gas-engine, the most efficient machine for deriving power from the heat of combustion. So constantly high is the efficiency of these engines for all types and sizes, that, in spite of higher investment costs, they offer to the small power user means of generating power as cheaply as the largest and most highly refined steam plant can do it.

As centralization of small steam plants has been practised in the interest of economy, the single large plant being more economical than the many small ones it displaces, so does the constant efficiency in all sizes, characteristic of the gas-engine plant, tend toward decentralization, offering to the factory owner, or small power user, a means of making power cheaper than the best large central station can sell it, and placing the isolated country power user in as advantageous a position as the city man who can get central station power if he wants it. The gas-engine, therefore, is the great leveler in the power generation field, its small and insignificant representative playing a part as important and independent as its more aristocratic large steam or water-power rivals. It is in point of efficiency the aristocrat of all fuel burners, surpassing in its few years of development the one hundred and sixty years' steam product, even though no attempt has yet been made to save or return waste heat in any way.

VII

WATER-POWER SYSTEMS AND BASAL HYDRAULIC PROCESSES

Wherever rain falls streams will form, the water of which represents the concentrated drainage of all the land sloping toward that particular valley at the bottom of which the stream flows. This stream flow consists of the rainfall over the whole watershed less the amount absorbed by the earth, or evaporated from the surface, and every such stream is a potential source of power. The possible water-power of a country or district is, therefore, primarily dependent on rainfall, but also, of course, on absorption and surface evaporation. In places where the land is approximately flat, the tendency to concentrate rainfall into streams would be small, as the water would tend to lie rather in swampy low pools, or form innumerable tiny, slowly moving brooks. On the contrary, if the country were of a rolling or mountainous character, there would be two important differences introduced. First, water would concentrate in a few larger and faster-moving streams, the water of which would represent the collection from perhaps thousands of square miles; and secondly, it would be constantly falling from higher to lower levels on its way to the sea. While, therefore, all streams are potential or possible sources of power, and water-power might seem to be available all over the earth, yet, as a matter of fact, only those streams that are large enough or in which the fall of level is great enough, are really worth while to develop; and only in those districts where the rainfall is great enough and the earth not too flat or too absorbent, or the air too dry, may any streams of useful character at all be expected. The power represented by all the water of a stream, and its entire fall from the source to the sea, is likewise only partly available. No one would think of trying to carry water in pipes from the source of a stream a thousand miles to its mouth for the sake of running some water-wheels.

It is seldom worth while to carry the water more than a mile or two, and frequently even this would not pay, so that only portions of streams may be considered as available sources of power. The power represented by any part of a stream is directly proportional to the product of the quantity of water flowing per second, and the difference between the levels at the beginning and end of that part of it under consideration, which difference in level is called the "hydraulic head." Any portion of a stream, then, in which there is a difference of head may be considered as available for power, the amount of which is measured by the quantity of water flowing and the head itself. Accordingly, a large stream carrying a great quantity of water, which falls only a little in level, may offer only a small power possibility because the head is so small, whereas a comparatively small stream, perhaps no larger than a brook across which a boy may jump, if it runs down the side of a high mountain, may make available at the foot thousands of horse-power due principally to the head. However the water may exist naturally, so long as it is in the form of a stream with a flow from a high level to a low, it offers an opportunity for power generation by concentrating the flow on wheels of suitable form; but it may easily happen that the returns from the development may not be worth the cost, while in other cases the cost of development may be richly repaid. Even though the water itself is regarded as costing nothing, and therefore as offering a certainty of cheap power, it must be remembered that it is not merely water that is needed for power, but water concentrated on to wheels, sufficient in volume and sufficient in pressure when it reaches the wheel. The cost of the water at the wheel where it becomes available for power will, therefore, be measured by the cost of the concentration process. Whether it will be worth while or not to carry out a development will depend entirely on the ultimate cost of the power produced, on the market for that power, and the cost of competing power generated from fuel. No one would be justified in concentrating the water of a waterfall into wheels if the cost of the power exceeded that produced from fuel by the steam or gas systems, nor would it be a sane thing to develop a power in the heart of Africa, where there is no demand for power within five hundred miles, no matter how cheaply that power could be produced at the spot. In every case the largest item in the cost of power per horse-power hour or per horse-power year is the fixed investment rate, representing the interest on the first cost of development or the cost of diverting the stream, concentrating its flow on to wheels, and providing means of control, so that floods, floating ice, and logs cannot injure the works. The definite yearly per cent of this development cost divided by the power produced gives a yearly, monthly, or hourly charge, which is the largest item in the cost of water-power, and may even be larger than the fuel and labor cost in steam plants, but, of course, may likewise be lower. It therefore appears that, assuming the stream to be available, representing possible power, it will be worth while to get that power only when the flow is large with perhaps moderate head, or when the flow is small with large head, and when, in addition, the cost of diversion and concentration is small enough, when there is a sufficient power demand or selling market available, and finally, when the cost of steam or gas power is high enough in that particular locality.

It usually happens that the cost of development does not stop merely with diversion and concentration of the water at the wheels, because rainfall is irregular, and so, of course, is the resulting stream flow, which fact introduces a necessity for storage reservoirs. The size and cost of these storage reservoirs will, of course, depend on the extent of the fluctuation of stream flow and on the time intervals. A district in which there is a very heavy stream flow for a few days, followed by a month of no flow, would require a reservoir large enough to hold practically the whole flood water so that it could be supplied uniformly to the wheels all the rest of the time. Such conditions as these might be found in tropical countries, where there are heavy rains extending over a season, followed by long periods of no rain, or might also be found in cold countries where during the winter all rainfall is frozen into ice or snow, and where in the spring there comes a great rush of water representing the concentrated rainfall of a large part of the winter, as the snow and ice melts. No two streams, representing power sources, offer quite the same problem of power development, the first step in which is the reaching of an intelligent judgment as to whether it would be worth while to develop at all or not, which judgment must be based on the most painstaking investigation of a multitude of conditions involving rainfall, stream flow, water storage, and power demand or market, together with estimates of the probable cost of the power to be produced and the cost of competing steam or gas power. Assuming that it has been found to be worth while, and it must be remembered that this step always contains an element of speculation, the next step is to decide how best to carry out the project of diversion, concentration, and storage of the water-power and the protection of the works from the unused or flood water, from ice or floating débris.

Seldom does it prove worth while to attempt to develop all the power available at a given section of a stream, because the cost of the works is always large; and if the installation is made large enough to use the maximum stream flow, then in time of drought or freeze-up, less power being available, a part or perhaps all of the investment will be idle and earning nothing; but even worse than this, those industries dependent on the power will be unable to proceed, and all the men employed by those industries will be thrown out of work, thus rendering the capital invested in the industries also useless. To protect dependent industries it will be safe to develop only so much power as is represented by the minimum stream flow, and to waste all the rest when there is no storage. In cases where the industry-demand for power exceeds this minimum supply, then the resource of a storage reservoir is available to a limited degree, after which auxiliaries, steam or gas power, must be installed, further complicating the problem. For when auxiliary fuel-burning power is used, it naturally is idle in times of

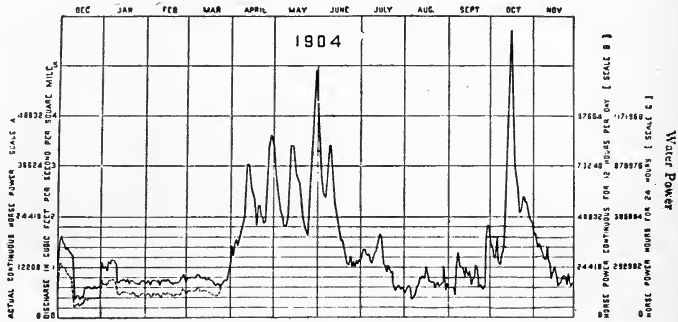

Fig. 164

heavy stream flow, which fact increases the cost of the power delivered. Furthermore, it might easily be far better for dependent industries to have their own steam or gas plants that could be worked all the time, instead of depending on a combined water and fuel plant, part of which must certainly be idle some of the time. Such difficulties as these all arise, of course, from fluctuating stream flow, which is violent in some places and practically non-existent in others, but generally present to a sufficient degree to make a good deal of trouble. Streams are studied by engineers and government officers with regard to their flow, and the results are made public records, either in the form of tables or curves, as shown in Fig. 164, prepared by Professor Mead to illustrate by the vertical height of the irregular line the variation in flow for each month of the year at Kilbourn, Wisconsin. It will be seen that the maximum flow is approximately seven times the minimum. The same thing is shown by the table prepared by J. F. Frizell, showing what per cent of the total yearly stream flow in Massachusetts is available for each month of the year. This is a particularly striking case because this district is not one subject to violent storms or droughts.

PER CENT OF YEARLY STREAM FLOW AVAILABLE IN EACH MONTH OF THE YEAR IN MASSACHUSETTS

January	16%	July	2%
February	14%	August	3%
March	20%	September	3%
April	15%	October	5%
May	10%	November	6%
June	4%	December	8%

From the table it appears that the minimum flow occurs in July and is only one-tenth of the maximum occurring in March, when the snow and ice are melting. If on a stream of this character power development be based on the minimum flow, only 2 per cent of the annual flow can be used per month, or 24 per cent of the total in the year. All the rest must be wasted. Even to use this 24 per cent of the yearly rainfall, storage reservoirs must be available, because for several days at a time the actual flow may fall below or rise above the mean for the month.

In general, stream-flow fluctuations are least when the watersheds feeding this stream are greatest in extent, because rain may fall in one section and not in another, the average for all being steadier than for any one. Sometimes these watersheds are very large. To illustrate this point, the following table is presented by Colonel Samuel Webber, and indicates the number of square miles drained for each of three sections of the Merrimac River, where 10,000 h. p. is available.

AREAS OF MERRIMAC WATER SHEDS

Manchester . .	10,000	49	ft. head	2709 sq. mi. watershed
Lowell . . .	10,000	33½	ft. head	4000 sq. mi. watershed
Lawrence . . .	10,000	28	ft. head	4600 sq. mi. watershed

He also estimates the rainfall for the United States as forty-two inches, about half of which gets into the streams, representing about 1,000,000 cubic feet per day per square mile, one-third of which total might be conserved by reservoirs if the cost were not prohibitive, rendering available about one cubic foot per second per square mile on the average for the whole country. Of course, much of this rain falls on low land and is useless. A large quantity either falls on dry sections, or the streams flow through dry sections where the evaporation is very severe. Cases are known where evaporation from a pond or river exceeds the equivalent of one inch depth per day. As a consequence only a very small portion of the rainfall is really available for power purposes; but by careful study and stimulated by changes in industrial and economic conditions, more and more can be rendered available and more and more than is now used may be profitably developed.

The study of water-power conditions is very old indeed, but it is only for the past fifty years or so that these broad aspects of the question of economic development, such as have been outlined, have received attention. The recent great progress is due partly to the fact that in the early days there were no wheels capable of using high heads; partly to the lack of market for power; but very largely because many of the most effective water-power sites were located off in the woods far from the towns, and with no transportation facilities between. With the increasing demands for power, due to the development of manufacturing and largely stimulated by the influence of the steam-engine, attention was directed to other water-powers than those early developed, and a better understanding of the principles of design enabled engineers to build suitable high-head water-wheels, so that a change in the water-power situation was inaugurated. The greatest factor of all, however, in this new and vigorous utilization of water-power came from the progress in electrical engineering, which showed how the power of rotating shafts could be converted into electrical energy, how such electrical energy could be made to flow without prohibitive losses or excessive costs on wires over distances exceeding 100 miles, and how at the end of a transmission line the electrical energy could be converted back into the form of rotating shaft power by electric motors, or converted directly into light by electric lamps. The creation of electric systems of power transmission, consisting of generators, line wires, and motors, has widened the limit of water-power application, and to-day water-power does not merely exist at the power house, but in fact is available at any point within a circle having a radius of one hundred miles. By this electrical transmission of water-power, progress in water-power generation and use has been stimulated to a degree that otherwise would have been impossible; for it is far cheaper to run wires over the mountains to towns already located, and in communication with the rest of the world by river or railroads, than to run railroads through mountain countries to permit of the establishment of a factory at the water-power site.

As a result of this latter period of economic development, the practice has more or less crystallized, and in reviewing the situation as it exists to-day it is convenient to divide those cases that have proved to be worth while into three typical classes with regard to the head, assuming, of course, that this head is available within not too great a horizontal distance. The first class will include low heads of 20 to 30 feet, in which case there would nearly always be involved a large quantity of water, because it would take a good deal of water with such heads to develop much power. The second class includes medium heads between 100 and 200 feet and with perhaps moderate or large flow; and the third class, heads up to or exceeding 1000 feet, in which case there need not be a very great flow to develop considerable power. In no case, as has already been stated, must the horizontal distance to secure this head be too great, and in practice it has been found that the abrupt head, such as occurs at falls of considerable height, is almost ideal, while a horizontal distance of two or three miles is not out of the question.

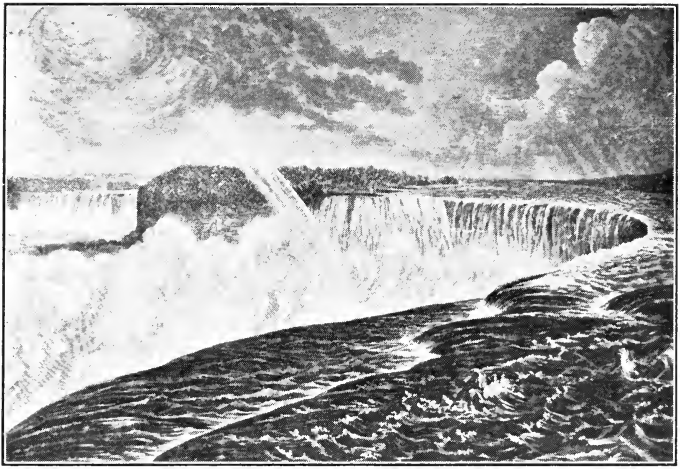

FIG. 165

To illustrate some of these typical cases a few pictures will be helpful. Perhaps the best-known large-flow, abrupt-drop, medium-head site is that of Niagara

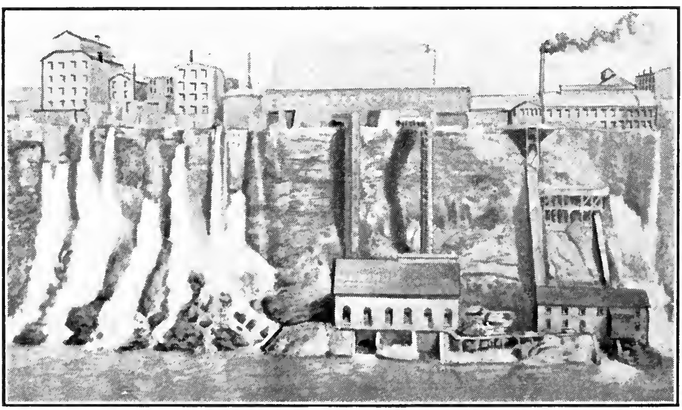

FIG. 166

Falls, shown in Fig. 165, taken from a point above the Falls and showing more particularly the great volume of water and the width of the fall. At this point the fall varies in height from 158 to 167 feet, and the width of the crest is about one-half mile, over which the volume of the flow is not exactly uniform. It is estimated that about 7,000,000 h. p. is available at this point, of which only a small portion is developed or under consideration. Another view of the Falls, taken from the gorge below some distance away, and showing some of the industrial plants that have grown up by reason of the power, is shown in Fig. 166. In this view a vertical pipe-line is clearly visible, conducting water from above to a power house below, where the head available is about 220 feet, and by means of which some 1500 h. p. is developed. Part way up the cliff, water can be seen spouting from the discharge of several water-wheels using only part of the head and so wasting some of the power. Another example of a still greater falls of much the same character as Niagara is shown in Fig. 167, representing the great cataract of the

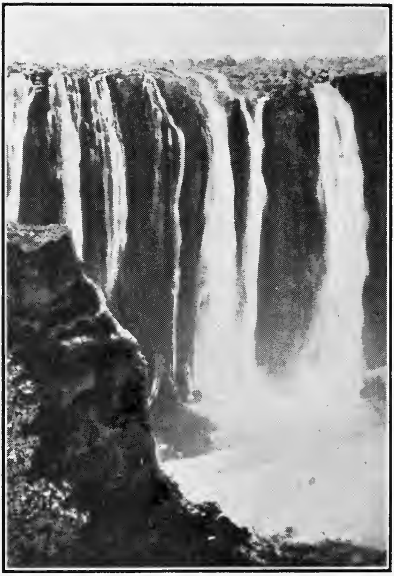

Fig. 167

Zambesi in Africa, still undeveloped because of lack of market or demand for power in that locality, although many projects have been formulated, some of which will ultimately be carried out. The illustration shows clearly the abrupt character of the drop, and the indications of the variable flow which characterizes this stream, in striking contrast to the almost uniform flow of Niagara. Here the height is a little over 400 feet, and it is estimated that in time of flood over 35,000,000 h. p. may be secured; but by reason of the tropical and irregular character of the rainfall, only a small fraction of this can be depended upon for steady generation. Another example of the same class of abrupt fall, but much smaller, though still large, is shown in Fig. 168, which is a view of the Montmorency Falls, about eight miles from Quebec, where there is now in use some 12,000 h. p. under a head of 275 feet. Part of the head works and gate-houses through which the water-power is diverted are visible at the top of the picture. An example of the somewhat scattered but

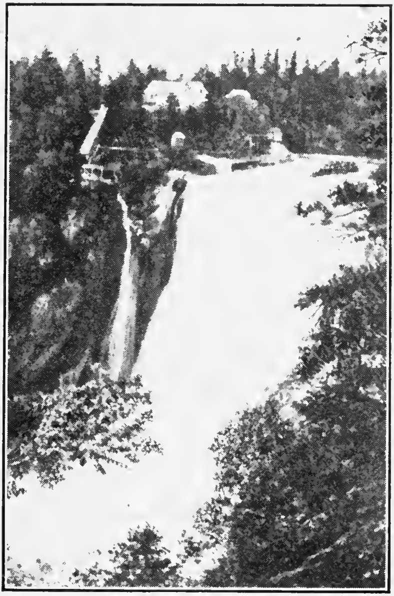

Fig. 168

still fairly high, though not so abrupt, fall is shown in Fig. 169, representing the city of Tivoli, Italy, where there is a head of 360 feet, of which, however, only 165 feet is used and some 2000 h. p. developed. The city above the falls is clearly visible at the top of the picture. These few examples will serve to illustrate that type of stream in which the volume of water is

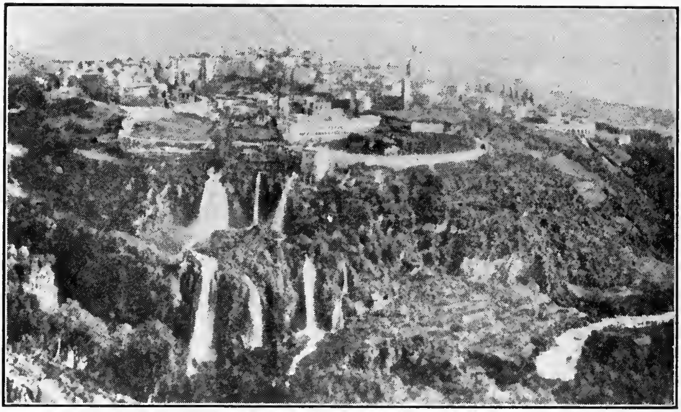

Fig. 169

considerable, the fall obtained in a very short horizontal distance, and the head of intermediate value, offering almost ideal conditions for power development.

Extremely high heads are available only in the mountains and obtainable only by more or less considerable horizontal distances. Development in these cases will, therefore, cover some miles of mountainous country, often involving the boring of rock tunnels and the construction of canals carrying water around the sides of hills, so that no single picture can quite show the nature of the problem. There is, however, presented in Fig. 170 a view of a pipe-line coming down the side of a high mountain and forming part of one of these high-head plants. This pipe-line has been installed by the San Joaquin Electric Co. of Fresno, California, to develop a head of 1400 feet, and 1000 h. p. is transmitted electrically 35 miles over the mountains. This pipe-line is fed by a canal seven miles long, the pipe itself being 4000 feet in length, indicating that a distance of seven miles was necessary to develop this head, a condition which would never have been justified unless so great a head could be available. Such high-head work through mountainous country is characteristic of our own Rocky Mountains, parts of Mexico, and the Swiss Alps, and is a direct result of the influence of electrical transmission, without which these isolated and inaccessible mountain streams would have been quite useless.

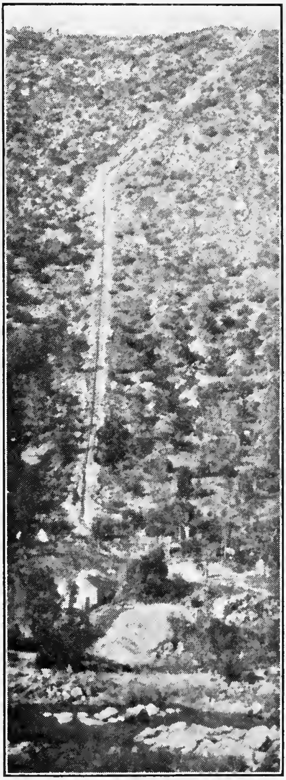

FIG. 170

The last of the three classes of streams and that first developed is the low-head class, where either at a low natural waterfall, or at the head of a section of the river where there are rapids, a dam is placed, fixing a high level for the water, the low point being located at some convenient spot down-stream, perhaps only a few feet or perhaps several miles away. Such a stream is illustrated in Fig. 171, which represents the German Rhine at Neuhausen. Here the river runs through a sloping stretch, making a rapid. Another stream having a similar rapids section is the Susquehanna River,

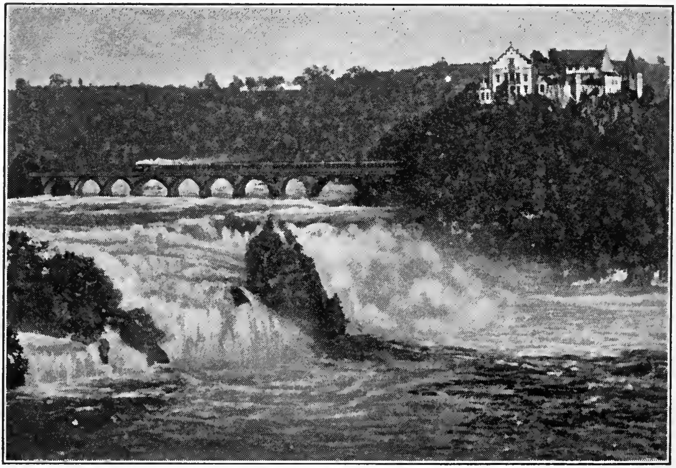

Fig. 171

recently developed at McCall's Ferry, at which point the river is 2700 feet wide, and drains an area in the Alleghanies of 27,400 square miles. The erection of a dam has made available a head of 53 feet, which, of course, varies from time to time. In time of flood the flow of water is 225 times as much as the minimum flow. This requires a large waste weir, or overflow dam, 2500 feet long, over the crest of which the flood waters will rise 17 feet. To indicate the power market that has warranted this development it should be noted that within a radius of seventy miles are located the cities of Philadelphia, Wilmington, Baltimore, Harrisburg, York, and Lancaster, for which there will be available by ten wheels about 140,000 h. p. The Susquehanna development is shown in Fig. 172, which is a map of the section. A photograph illustrating the magnitude of the construction work necessary

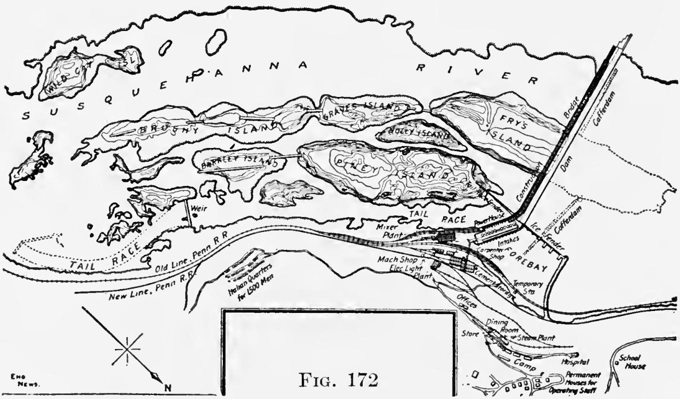

Fig. 172

to the dam is shown in Fig. 173, while the flood difficulties are shown in Fig. 174, representing a flood through a partly completed section of the dam, submerging much of the construction equipment there located. Still another case of low-head development is that on the Tennessee River below the city of Chattanooga, the location of which, with respect to the dam, is shown on the map (Fig. 175), from which it will appear that the dam is many miles below the city, while the stream runs through sections of low land and through narrow valleys between high banks. The creation of the dam

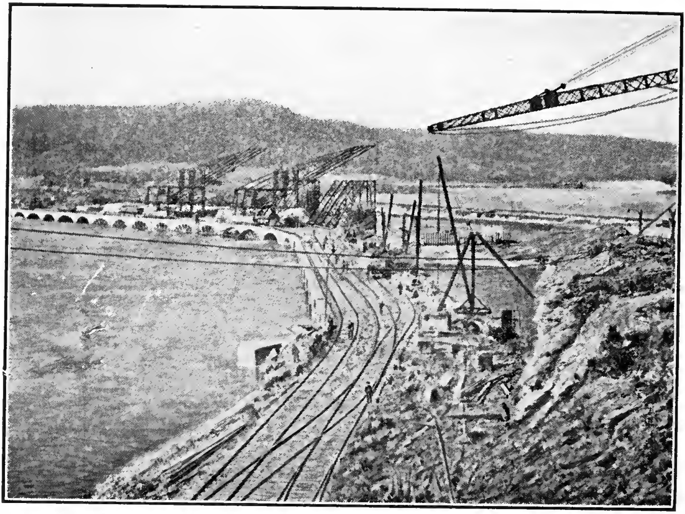

Fig. 173

causes the water to rise in this stream for some thirty miles above, although the head is available through the abrupt fall created at the dam itself.

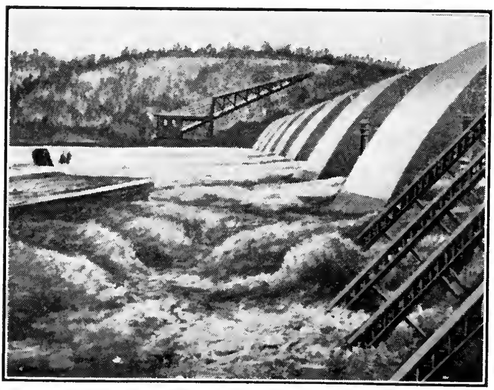

Fig. 174

In the early days of American development only low heads were attempted, and on the sites chosen cities grew. These low heads were selected because of the prevailing form of water-wheel, which was the familiar old mill overshot or breast type, completely exposed and of diameter approximating the height of the falls. These wheels were located first at either the side of a natural fall or at one end of a dam built above a fall or rapids. When more power was wanted, another mill with its wheel was located at the other end of either the fall or the dam; and when more than this supply was wanted, there began canal construction. A canal was excavated on the high ground on a level

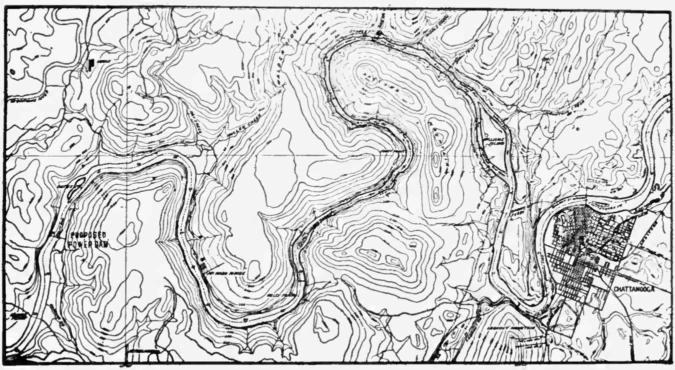

Fig. 175

with the upper waters, and sometimes also another one through the low ground at a level with the lower waters. Between these two canals any number of wheels could be located and any number of mills established. Where the ground was sloping between the high and low-level canals, wooden boxes or flumes were built out and supported on posts to bring the water directly over the wheel, from which it discharged into the tail canal. In those cases where the head was so high as to demand very large wheels, say 30 feet in diameter, another intermediate canal was built, and smaller wheels, of half the diameter, located at intermediate points. The water from the high-level canal would run from one wheel into the intermediate canal, and from there to a second wheel into the low level. This sort of development was carried on for many years and was the first attempt. According to Colonel Samuel Webber, the first water-wheel to be erected in this country was built in 1790 at Pawtucket Falls, for cotton manufacture, and was soon followed by others at Paterson, New Jersey, in 1813 at Fall River, Massachusetts, and in 1821 on the Merrimac River for operating both a machine shop and a cotton-mill at a point which afterwards became the city of Lowell. At the point on the Merrimac River the two-canal system was used, with two drops of 13 and 17 feet respectively, to accommodate the small wheels to the 30-foot head. A similar canal development, but with three levels, took place at a point in the Connecticut River where is now located the city of Holyoke, Massachusetts. The arrangement of these canals is shown on the map, Fig. 176. At this point there is a total head available of 61 feet, developed for a distance of 3250 feet below the dam, where there are now at work some 60 mills, using about

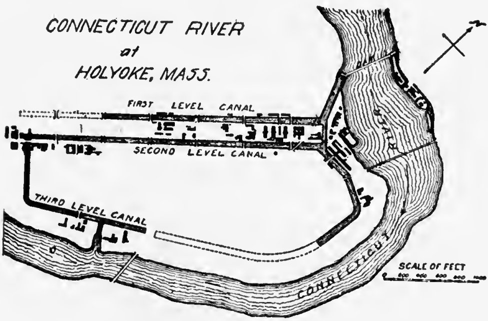

Fig. 176

30,000 h. p. by day, and half as much at night. Perhaps the first tendency toward the changing of conditions was the result of steam competition, which appeared in 1830, at which time the first steam-engine mill was erected at Providence, Rhode Island, and it is an open question whether this competition did or did not tend to stimulate the study of water-power; but whether it did or not there was applied fourteen years later, at the Appleton Mills in Lowell, 1844, the first hydraulic turbine. This turbine, typical of all future development, was capable of making more effective use of any head of water than were the old wheels; and it, moreover, could be built for high as well as low heads, and could be supplied with water through pipes over or under ground, making canals unnecessary, except in those cases where they were already installed, or where their construction was cheaper than pipe-lines of the same water capacity. These turbines make use of the spouting capacity of water under pressure as it issues from the pipe or nozzles connected with the pipe. The water-jet, as already explained, works in connection with curved vanes, operating them by giving up its velocity, an action which distinguishes them from the old and most common overshot wheels, where the water turns the wheel by its weight alone. It is worth while to review the principles of these turbines, which had the effect of changing water-power development methods, and which

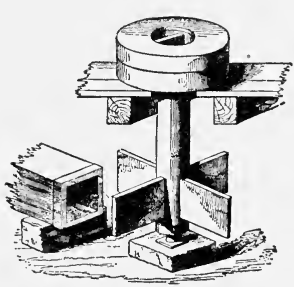

Fig. 177

were not built in this country until 1844. In Fig. 177 is shown a crude Indian affair, acting by impulse. Water issuing from the wooden pipe has a certain velocity and direction, and by impulse on the wooden vanes turns the wheel. A more recent form and better design, though still an old one, is shown in Fig. 178, in which gates are provided to control the water. The spout is tapered to get a better form of jet and the vanes are curved to get better effect on the wheels.

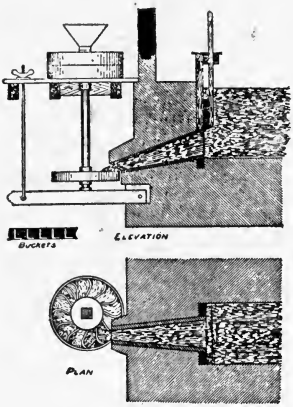

FIG. 178

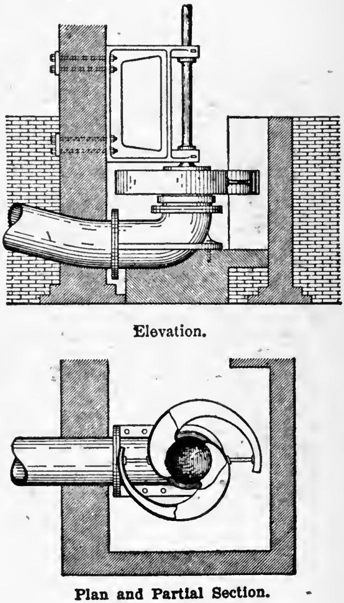

FIG. 179

This design is fundamental to the modern impulse wheel. A similar simple wheel of earlier times, containing the essentials of the modern reaction wheel, is shown in Fig. 179, in which the water is brought to the hollow interior of the wheel by a pipe leading upward to its center. Water escapes from the hollow interior through nozzles bent so as to make the discharge tangential and rotating the wheel by reaction. Modern water-wheels designed with nozzles and curved vanes act on both reaction and impulse, and sometimes by both in the same wheels, and are no more than refinements of these simple affairs which started a movement completely revolutionizing water-power development some years ago. In order to show clearly how

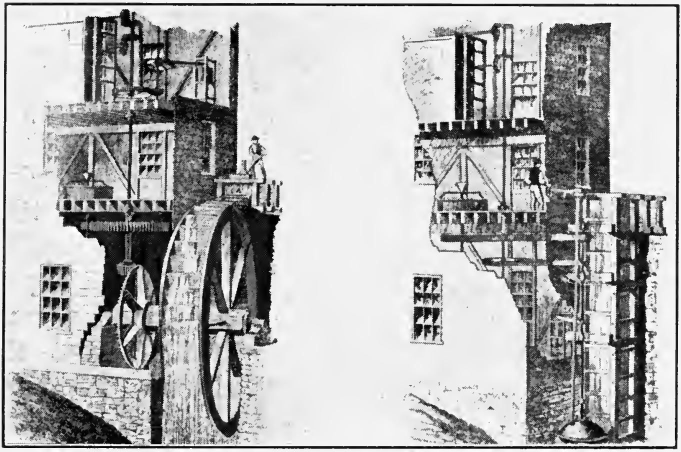

Fig. 180

the turbine installation compares with the overshot water-wheel installation, which it began to replace at that time, there is presented Fig. 180. Here there are two parallel installations for the same head of water, the water being carried from the stream to the wheels through an open wooden box or flume. It will be observed that the overshot wheel spills most of its water part way down, so that the water, which acts only by its weight, is available for only part of the fall, in fact, only a very small portion of it is available for all of the fall. For the turbine a vertical box is attached to the flume, and at its bottom all the water escapes through jets in the turbine with a velocity due to the whole head or fall, so that if the vanes are rightly formed and run at the right speed, fully 80 per cent of the possible effect can be obtained. Moreover, the water could have been brought to the turbine by a pipe over the whole distance instead of by canals, thus making possible great flexibility of construction, no matter what the head. Modern turbines are carefully designed and somewhat elaborate machines, especially when they are built to run electric generators, which require great steadiness of motion accomplished only by very elaborate governing apparatus in addition to fine design. A few examples of these will be shown to indicate general form and appearance, but the principles of detailed design are too technical to be gone into here. In Fig. 181 are shown three small tur-

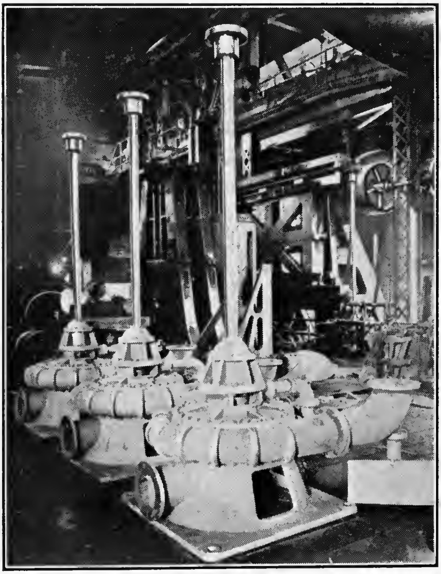

Fig. 181

bines on vertical shafts as they appeared in the shop, inlet and discharge pipes being clearly shown. The largest turbine ever built, and designed also for a vertical shaft operation, is shown in Fig. 182, the size of which may be judged by comparing with the ladder at the left, which is faintly visible. It develops 18,000

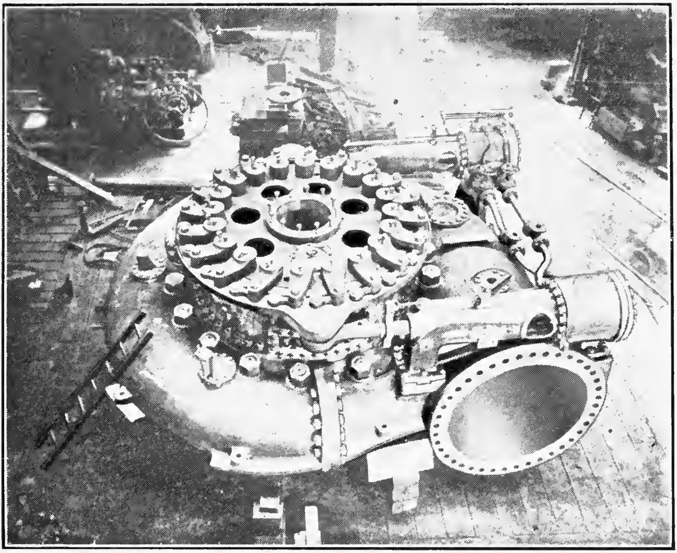

FIG. 182

h. p. in a single wheel, and is one of four built by I. P. Morris Co. for Great Western Power Co., for 525 feet head and nearly 90 per cent efficiency. This particular picture is interesting by reason of the fact that there is clearly visible at the top of the machine a series of levers operating the gates for closing off the water which enters the pipe shown and so regulating the power. These levers are all attached to a ring having two lugs at opposite points on the side, to which are attached the rods of two hydraulic pistons. By supplying pressure water to these cylinders, the pistons, rods, and levers may be moved, and this movement is controlled by the speed of the machine through a governor. These gates are rather heavy in large machines and offer considerable resistance to opening and closing,

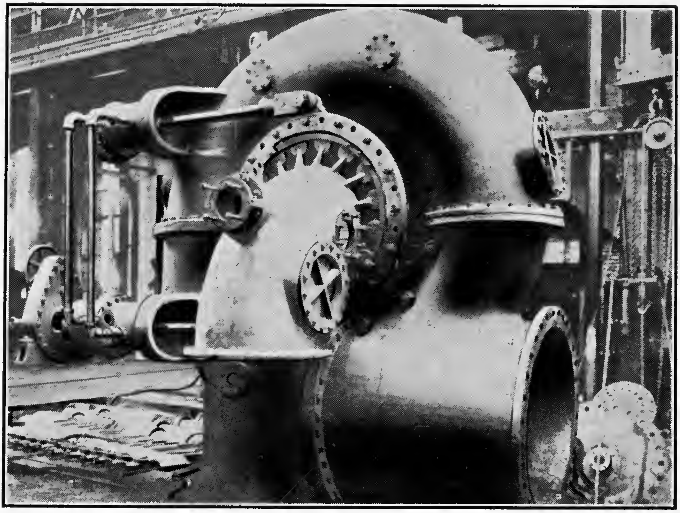

Fig. 183

and it is for this reason that hydraulic cylinders like these are provided to utilize the water pressure to accomplish the change of gate position. A smaller machine, designed for a horizontal shaft and also completely cased in, is shown in Fig. 183. Here the hydraulic cylinders are also present but the gate levers are not visible. Another horizontal shaft machine is shown in Fig. 184, in which the wheel proper is exposed beyond

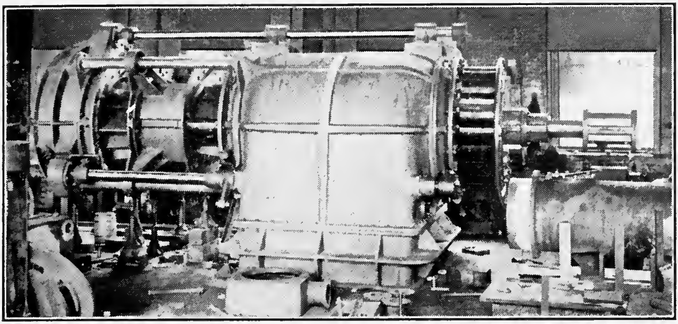

Fig. 184

the casing. This particular machine is capable of developing some 200 h. p. under a head of 30 feet, and is built for the Hanford Irrigation & Power Co. in the state of Washington, by the Allis-Chalmers Co. The wheel proper, or runner, of one of another type of turbine is shown in Fig. 185, from which it will be clear that the vanes are sometimes quite complicated and curiously curved, and yet these curvatures are very carefully worked out on hydraulic principles. Two turbines provided with wheel runners of this kind just mentioned, built by the Samson Co., are illustrated in Fig. 186, one of which is provided with a casing complete, while the other is only partly cased. In the latter form the water supply is not

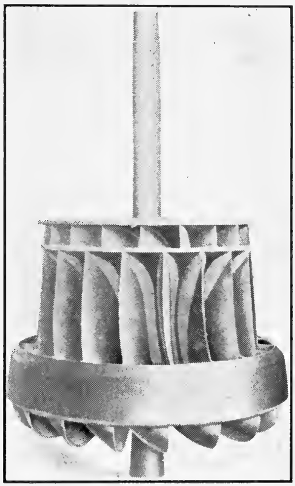

Fig. 185

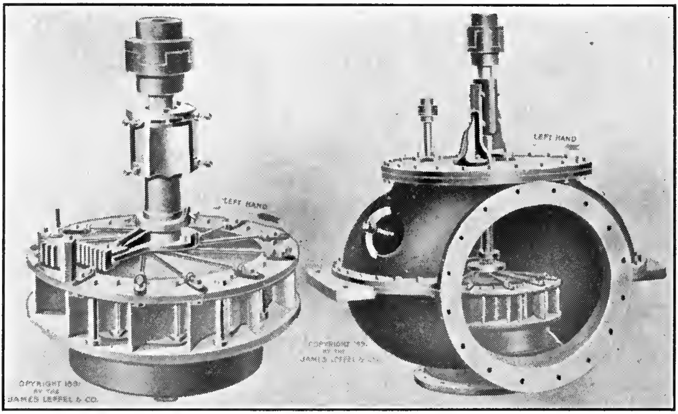

Fig. 186

piped to the wheel, although the discharge is piped away. A large wheel of this same construction, designed to operate in one of the plants of the Niagara Falls Power Co., is shown in Fig. 187, and develops 1500 h. p. under

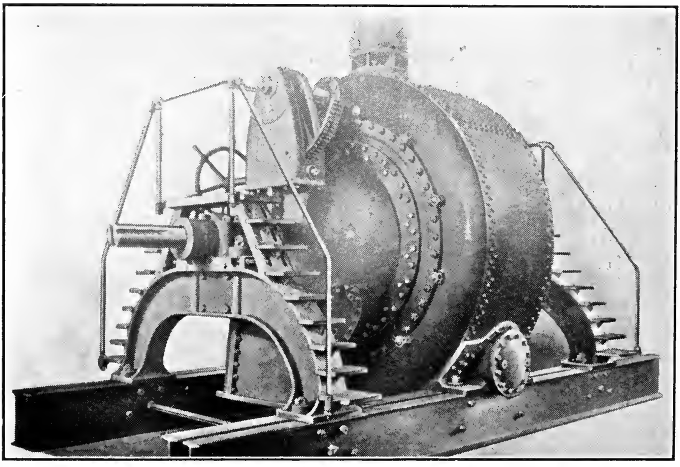

Fig. 187

a head of 220 feet. An extremely large wheel, designed for a vertical shaft and developing 13,000 h. p., is shown in Fig. 188 as designed for the Electrical Development

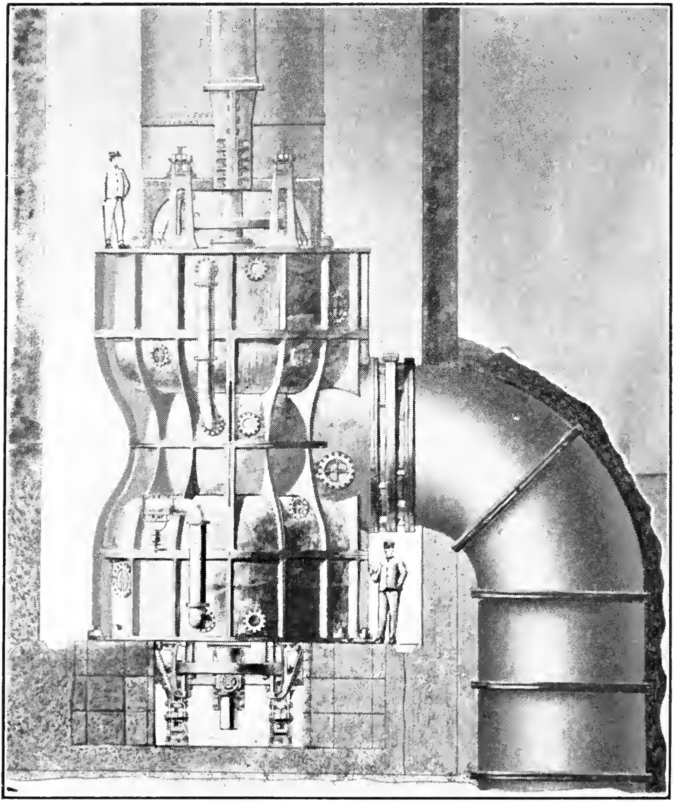

Fig. 188

Co. of Ontario. As a matter of fact, this wheel is two wheels within one casing, each receiving water from the same pipe, shown in the background, and both discharging to the center to a common discharge pipe, shown at the right. This is one of eleven installed at Niagara Falls for a head of 135 feet, each supplied through riveted steel pipes 10 feet 6 inches in diameter.

From the constructions shown it will appear that the water may be led to these turbines through pipes, or they may be submerged in the head waters above the dam; they may be run with vertical or horizontal shafts; all have vanes and nozzles, although the nozzles may themselves look like vanes, as is the case with steam-turbines. The direction of flow may be up or down, in or out, in practically any convenient way, making their application by reason of this flexibility a comparatively easy thing. In all cases the water acts over the whole circumference of the wheel, and whether it enters through guide vanes to ultimately discharge through nozzles, as in reaction wheels, or enters nozzles directly to strike vanes later, as in impulse wheels, the nozzles themselves form a continuous ring and are made by inserting partitions of suitable form between plates; the waterspaces between the partitions constitute the nozzles.

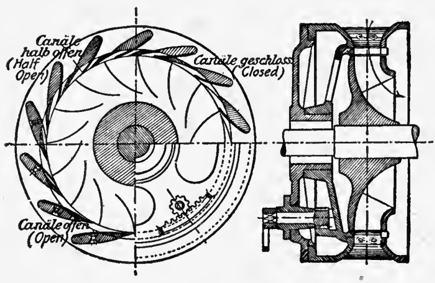

Fig. 189

To regulate the quantity of water passing through these, nozzles gates are always provided, and a water-wheel that is not provided with gates for regulating it is practically useless for electrical operations, as control of speed is quite essential. These gates are of three classes, known as cylinder gates, register gates, and wicket gates. In Fig. 189 is shown a wheel provided with register gates. These register gates are really a series of specially formed covers that slide over the nozzles of the wheel by a movement about the circumference. In the figure the gates are shown in three different positions. In the upper right-hand position the nozzles are completely closed. In the upper left-hand position the nozzles are partially open. In the lower left-hand position they are completely open. To move these gates around so that they cover or uncover the orifices, a ring is provided with gear teeth and a small gear attached, as shown in the lower left-hand corner. Instead of sliding something around the circumference to close the opening, as is done with the register gate, a thin cylindrical shell, somewhat like a piece of pipe, may be slipped in between the fixed and moving part of the turbine, as is shown in Fig. 190, which represents a cross-section of one of the 5500 h. p. turbines of the Niagara Falls Power Co. The two heavy black lines at the center

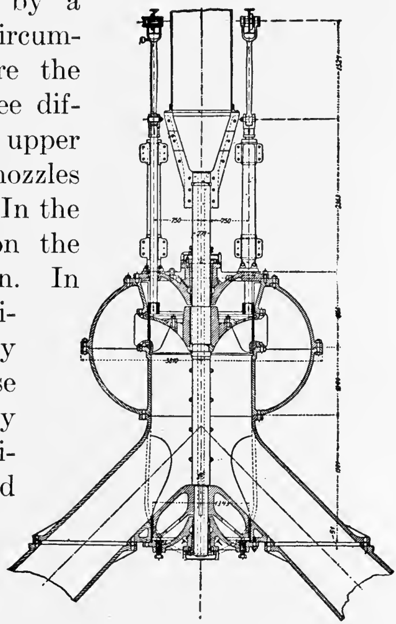

Fig. 190

represent a section of the cylinder gate plate. By lifting this cylindrical shell up and down, the size of the water-passage may be controlled. Instead of lifting a cylinder up or down, as is done with the cylinder gate, or instead of sliding a row of covers over the nozzles, as is done in the register gate, curved partitions may, as in the wicket gate, be pivoted. Such a wicket gate is shown in Fig. 191 attached to a small 100 h. p. turbine of Swiss design. Each partition is formed somewhat like a shoe and has a pivot at its center. By rotating each about this central pivot the space between may be made narrow or wide, but still will constitute a nozzle directing the water in approximately the same desired direction.

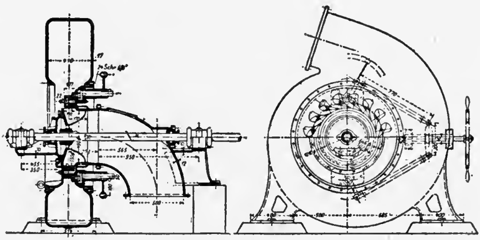

Fig. 191

The movement of these gates, whether they be cylinder, wicket, or register type, is always under the control of governors, which are themselves quite complicated machines, one of which is shown in Fig. 192, the details of which need not be gone into here; but it must be realized that governing is an important factor in successful water-power work, and that it is a difficult problem.

When gates are closed to reduce the quantity of water passing through the wheel, the whole quantity of water in the pipe must be reduced in speed. This water is practically incompressible, and the slowing up of this long column without danger is just as difficult a proposition as stopping a high-speed train. If gates be suddenly closed at the end of a long pipe-line, the water will tend to continue to move by its own inertia, so that the pressure at the gate will momentarily rise, and may become very high, so high, perhaps, as to burst the pipe or injure the wheel. In the case of the Fresno

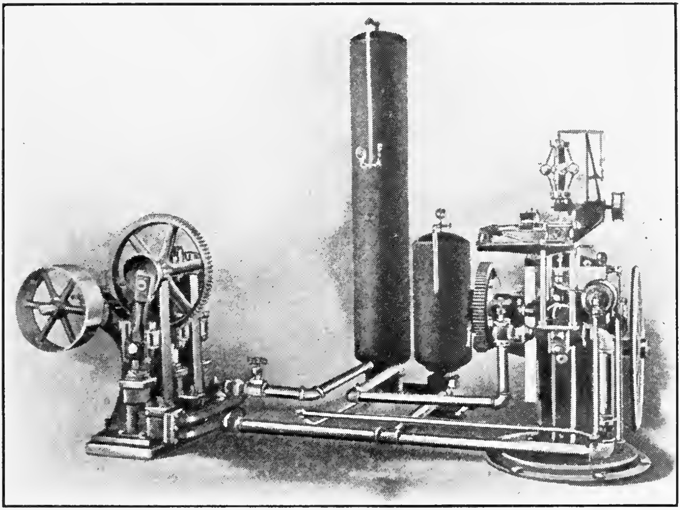

Fig. 192

Power Plant, already referred to, the weight of the water contained in the 4000 feet of pipe, having diameters at the beginning 24 inches, and 20 inches at the end, is 317 tons. If the gates were suddenly closed on this pipe-line, the 317 tons of water would be suddenly stopped, and something would happen, and that something would mean a wreck, unless the pipe were made unusually thick, or some safety element provided.

To avoid this difficulty relief-valves are sometimes used, something like the safety-valves on boilers, but they are not considered as reliable as another device, which, however, cannot be used on very high heads. This other device is a stand-pipe projecting up in the air near the power house. Under ordinary flow conditions the water would not run out at the top, but should the flow of water be suddenly arrested, the water would spout out at the top, as shown in Fig. 193, illustrating two stand-pipes, one of which is discharging water, and the other is not.

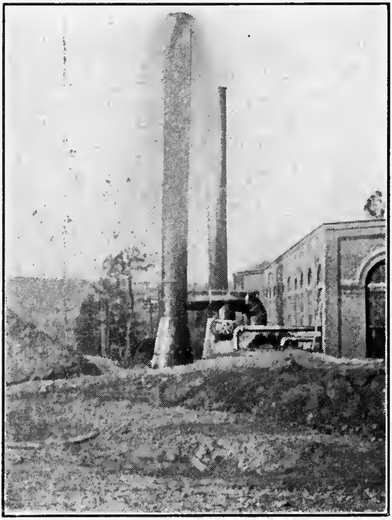
Fig. 193

The horse-power of a turbine is some fraction of the product of the quantity of water flowing and its head or pressure. This fraction is the efficiency, or the ratio of the power that the turbine can develop to the energy of the water passing through, and in good wheels this is about 80 to 90 per cent. The area of the passages through which the water flows must be large enough to pass just the right amount of water, so that for low-head work, when much power is to be developed, the orifices must be large, and the water passages in the wheel also. On the contrary, for very high-head work the quantity of water needed to develop the same power is very much less, so that the areas of the nozzle passages must be quite small. As a matter of fact, for very high heads, approaching 1000 feet, a wheel of suitable diameter would require a total nozzle area too small to permit of construction and control if the nozzles extended all around the circumference of the wheel, as each nozzle will be a mere slit no wider than the blade of a knife. Therefore, for high-head work all the water, instead of entering the wheel over the whole circumference, is concentrated in one, two, or three nozzles, generally one directed toward the wheel, which is, therefore, always of the impulse type. These high-head wheels, designed for single nozzles, are differently formed from the other turbines noted, and consist of disks carrying on their circumferences a series of buckets, such as shown in Fig. 194, which illustrates a wheel to develop 500 h. p. at a head of 865 feet. A series of impulse-wheels of the same general class, but differing structurally, is shown in Fig. 195, as installed in the San Joaquin plant, the jet striking the buckets of the wheels underneath. To control the speed of these wheels and at the same time to avoid setting up heavy inertia pressures in the pipe-line by varying the quantity of water, it has become customary to deflect the nozzles so

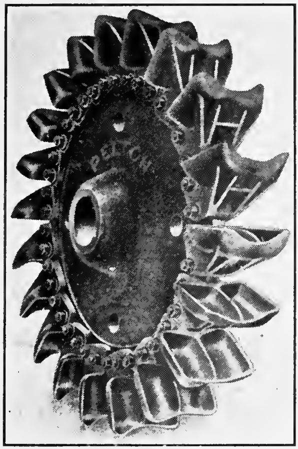
FIG. 194

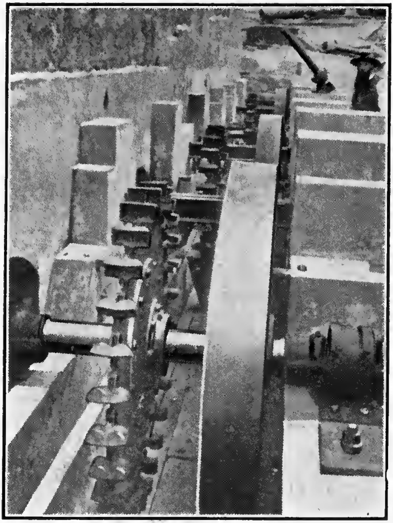

Fig. 195

that the jets strike the buckets more or less. Such an arrangement is shown in Fig. 196, in which the nozzle is carried from a lever controlled by the governor, so that when the speed gets too high the nozzle is dropped away from the wheel. This allows the regulation of speed desired, without varying the quantity of water, and therefore injuring the pipe. It is interesting to note in this connection how concentrated is the jet. Such a jet is shown in Fig. 197. It looks like a bar of polished steel, and if directed against a man would pierce his body, as would a projectile from a gun.

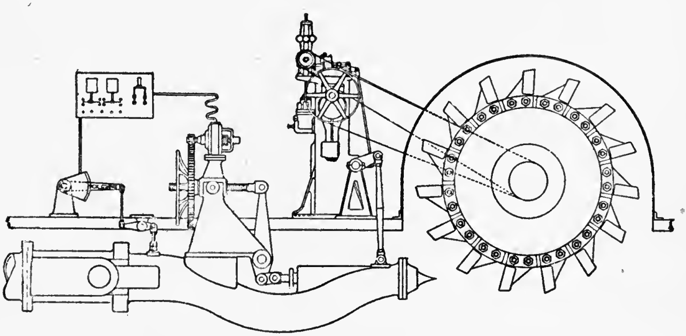

Fig. 196

It is, therefore, a thing to be carefully guarded and perfectly controlled.

Wheels being available for any head, however great or small, and a locality likewise available for a flow of water with a suitable head that can be developed within a reasonable distance, small if the head is low, large if it is high, the problem becomes how best to adapt the wheel to the locality, or how best to modify the locality to receive the wheel; the modification in every case involving concentration of the flow of water, or as much of it as is to be used, the providing of storage to take care of fluctuations in the flow, and the providing of safeguard against the destruction of the wheels. Unless there is a direct fall, there must be a dam, the object of which is to fix the high level and to store water. In connection with the dam there should be at one side, or at some other point in the stream, a spillway over which waste water coming down in time of excess of supply or of flood may flow without injuring the plant. At Niagara, the falls themselves constitute a natural spillway, whereas at McCall's Ferry, as has been noted, there was required a half-mile spillway dam. Dams are made in all sorts of ways, from earth and rock reinforced by timber, from masonry, or from concrete running down to bed-rock, and may, there-

Fig. 197

fore, be cheap or expensive. They may vary from only a few hundred feet in width to nearly a mile. A timber and cribwork dam of the Animas Co., in southern Colorado, is shown in Fig. 198. At this point about 4000 h. p. is developed with a head of approximately 1000 feet. The water is led from Cascade Creek to this dam through a wooden flume, the reservoir back of the dam covering about 960 acres, the dam itself, 550 feet long, 75 feet high, extending 33 feet down to rock. Another dam, built of concrete with stone spillway, is shown in process of erection in Fig. 199 on the Chattahoochee near Columbus, Georgia. This dam is $33\frac{1}{2}$ feet above bed-rock, and controls a head

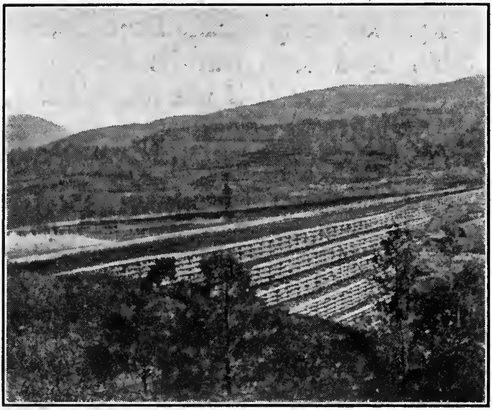

Fig. 198

Fig. 199

of 40 feet, at which some 25,000 h. p. will be developed from the drainage of 3500 square miles. From above the dam, or natural water basin, if there is one instead of the dam, the water is led to the wheels in a great variety of ways. The wheels may even be within the dam itself, the casing being removed from the supply side and the inlet orifices exposed to the standing water; or the water may be led through wooden flumes, masonry canals, rock tunnels, or vertical shafts bored in the rock, or through iron or wooden pipes. Somewhere in the open conduit there is usually provided a sort of basin called a forebay, to which the head-gates are attached, so that the water may be shut off for repairs; there will also be placed at this point rubbish or ice racks to intercept floating ice or logs. Whenever there is an upper level canal it is called a head-race. Below the wheels a canal is needed sometimes to reach the lower level waters, and in such cases it is called a tail-race. Before looking at some of the standard constructions for these various elements it will be interesting to examine some diagrams and possible general arrangements. In Fig. 200 are shown five diagrams of stream development, prepared by Professor Mead, lettered *A* to *E*. In the first one,

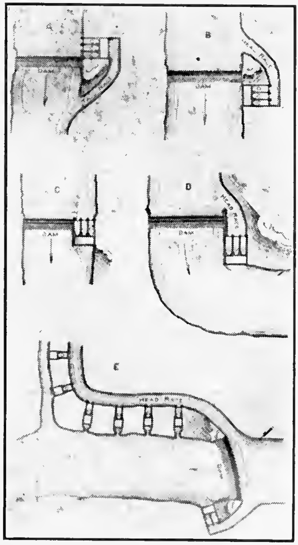

Fig. 200

A, there is practically no head-race, gates and wheels being located on the high ground above the dam, and as the surface slopes away rapidly in all directions a tail-race is excavated. In position *B*, the land is all high, so that instead of excavating to the depth required for a tail-race there is instead a head-race excavated, and the wheels are located on the steep bank, discharging directly into the stream. The land sloping rather abruptly from the bank necessitates a construction as shown at *C*, where the wheels are located in a down-stream extension of the dam itself, or that shown at *D*, which is practically the same thing. In diagram *E* the land is so located as to permit of the easy construction of a long head-race parallel to the down-stream part of the river, and between this head-race and the lower banks of the river many wheels are located. This is really a diagram of the old-fashioned canal development arrangement. Bends in streams are often favorable points to develop, especially when the bend is sharp. Three such possible arrangements are shown in Fig. 201, differing only in the contour of the location of the land. In the upper diagram the land is high but comparatively level for about half way. It then rises high so that

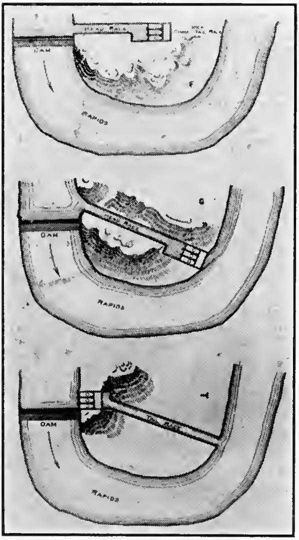

Fig. 201

a head-race is economical for half the distance, after which a tunnel and shaft are constructed to reach the tail-race. In the second diagram the land is high for nearly the whole distance, and then slopes down to the water, so that a head-race would be constructed the whole way and the wheels be located on the down-stream bank. In the third diagram the land is high for only a short distance. It then slopes down rapidly and is low for all the rest of the distance. In this case the wheels are located next the dam and discharge into a tail-race, excavated across the rest of the point.

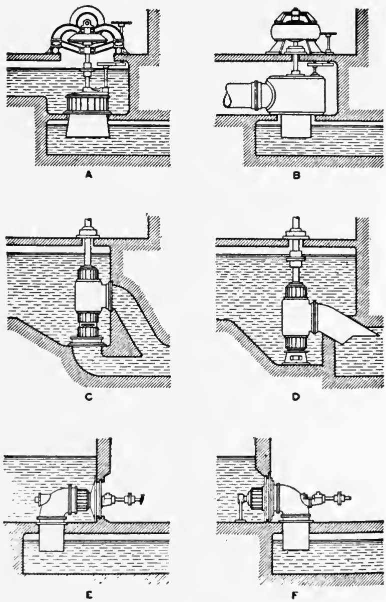

Fig. 202

Wheels may also be located in a variety of ways with respect to the dam itself, or to the low, pipe-line, penstock, and tail-water, as shown in Figs. 202 and 203, also prepared by Professor Mead. The first of these arrangements, that shown at *A*, is that of a vertical shaft turbine, the inlet orifices of which are incased and submerged in the shallow high-level water, the discharge water passing through a casing submerged in the tail-water. This is a typical arrangement for a very low head, to utilize every inch of height of the downward projecting tube, and is called a draft tube, as it acts much the same as a suction. At position *B* is shown the same arrangement except for high heads, in which case the water is brought to the wheel by a pipe and the upper part is surrounded by a casing.

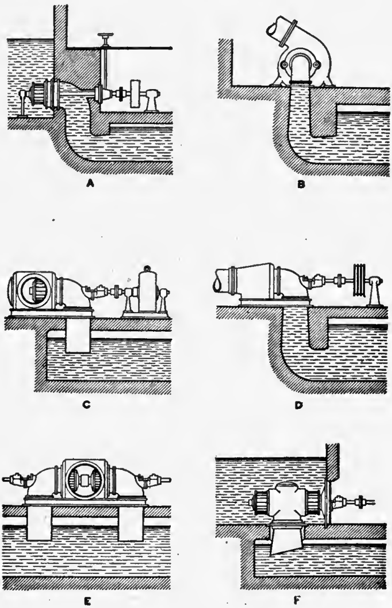

Fig. 203

Three wheels on one shaft of the open inlet submerged character are shown at *C*, with two discharging draft tubes. Two wheels on one shaft with single discharge draft tube are shown at *D*. In both cases the shafts are vertical. Two cases of horizontal turbine shafts with exposed inlet submerged are shown at *E* and *F*. In the former case the whole wheel is under the water and in the latter case only the inlet. Both have draft tubes.

Referring to Fig. 203, there are shown six arrangements of horizontal shaft turbines, in the first of which the whole machine is submerged and the draft tubes are constructed of concrete. In *B* the wheel is inclosed and rests on the power plant floor, and is supplied with high-pressure water through a pipe, but discharges through a masonry draft tube as in the former case.

In the next two cases, *C* and *D*, horizontal turbines completely incased receive water under pressure through pipe-lines, and discharge through draft tubes in the tail-water. In the former case, the draft tube is of metal, and in the latter built in the masonry. The same construction as that shown in *D* is used at *E*,

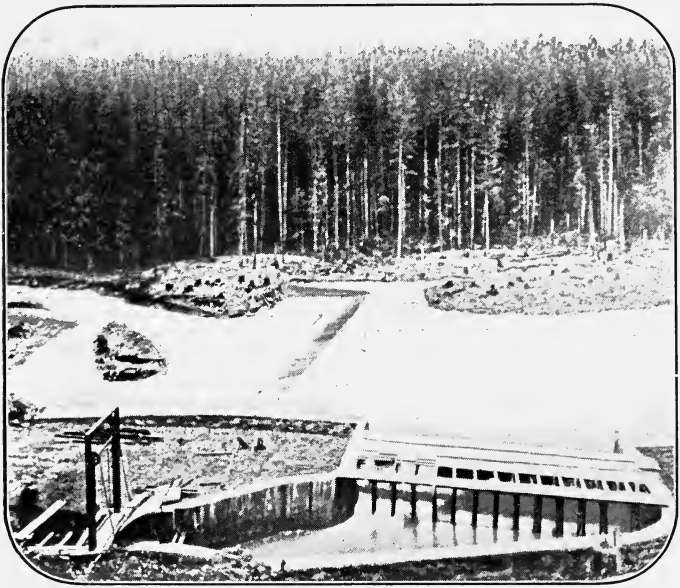

FIG. 204

except that the two turbines are supplied from a single pipe-line in opposite directions, discharging through two draft tubes; while at *F* the construction is especially adapted to low-head working; the two turbines are without any casing for their inlets and are, therefore, submerged, while a common discharge leads to a draft tube on the lower level.

Returning now to some of the typical constructions of the water conduit systems, there are shown in Fig. 204 a small forebay, waste dam, and canal inlet gate. Near the intake of the forebay there will be located some sort of screen to keep out logs and floating ice. This illustrates the intake of the Puget Sound Power Co. on the Puyallup River. The waste dam is 200 feet long, and the intake 62 feet wide in the river bank. Water entering this forebay and canal is conducted about 10 miles, finally drops 872 feet, and develops 10,000 h.p. The canal is only 8 feet wide and 5 feet deep. An example of head-gate arrangement for a comparatively small-sized plant is shown in Fig. 205, and represents the outlet at the Great Jezero Lake

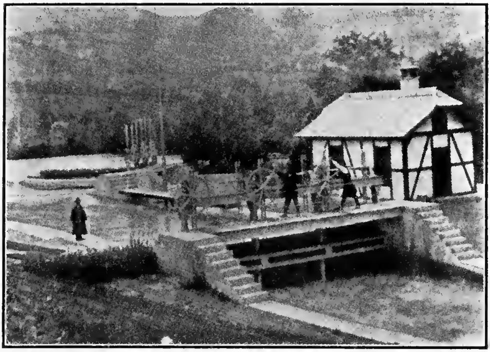

Fig. 205

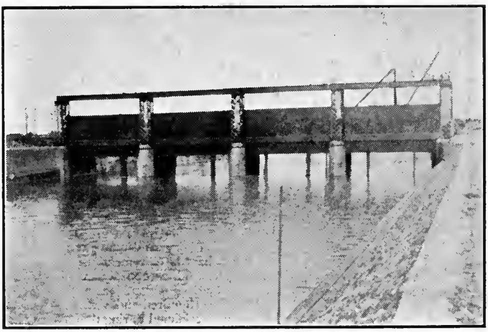

Fig. 206

in Europe. The water flowing through these gates ultimately develops 9000 h. p. A still larger gate is shown in Fig. 206, through which are led the waters of Lake Superior, which has an area of 30,000 square miles, escaping naturally through the Sault Rapids, some of which, however, has been diverted through this canal for the generation of about 60,000 h. p. under a head of about 16 feet by submerged wheels which are shown in Fig. 207. Just before reaching the

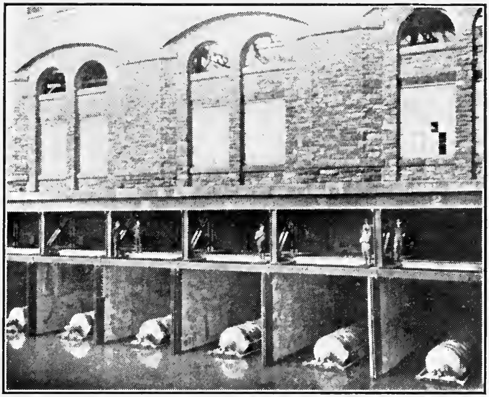

Fig. 207

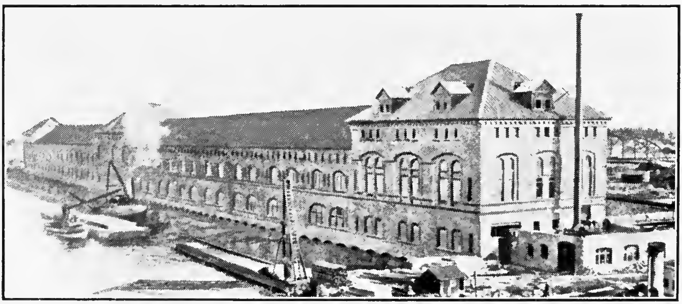

Fig. 208

wheels, the canal expands into a forebay 1400 feet wide, at the end of which is located on one side the power house, and on the other the spillway. The complete power house is shown in Fig. 208, and the ice-racks

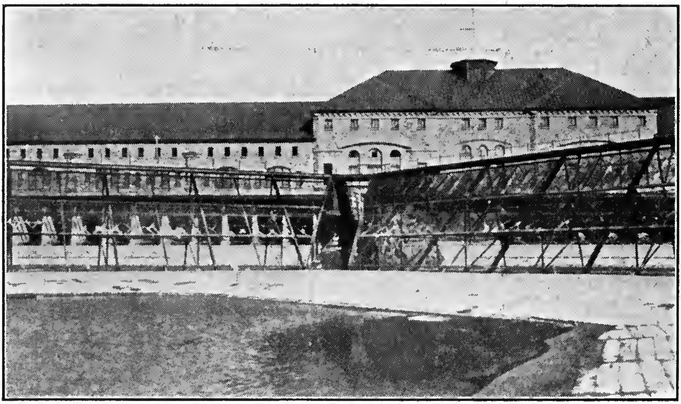

Fig. 209

in Fig. 209. A somewhat more elaborate arrangement for controlling the water is that used by the Ontario Power Co. at Niagara Falls, shown in Fig. 210. This

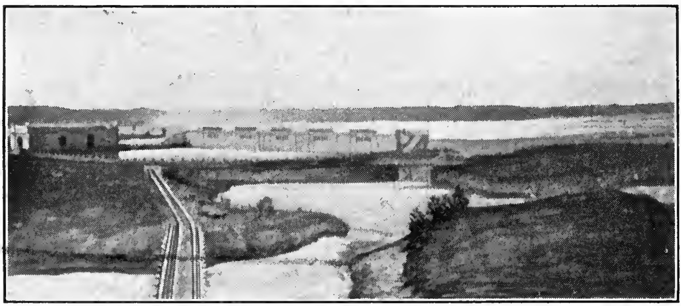

Fig. 210

is a beautifully executed hanging wall of masonry under which the water must flow.

These few illustrations will serve to show the variation in structure of head works, including forebays, gates, etc.; but before the water, the diversion of which is started at the head works, can become available it must be conducted some distance. This requirement is most commonly carried out first by canals and later by pipes. A common earth canal is shown in Fig. 211. A crude sort of conduit or flume

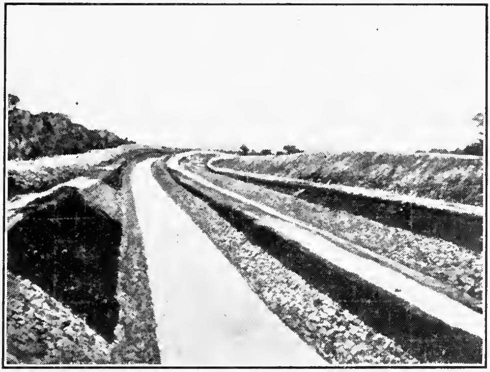

FIG. 211

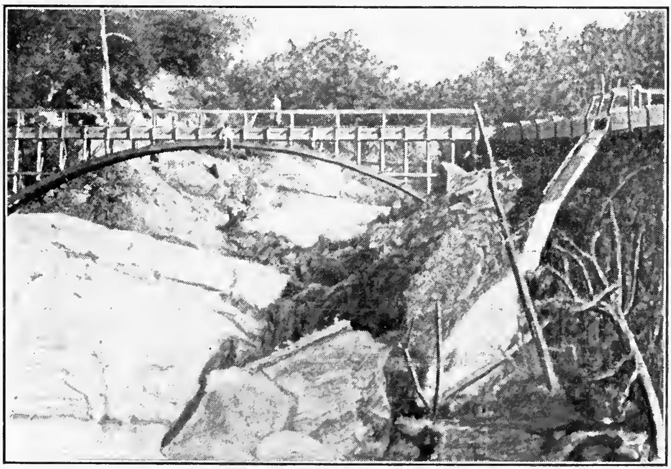

FIG. 212

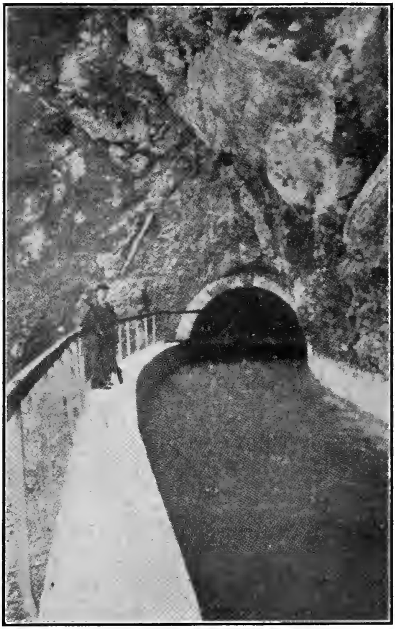

FIG. 213

made of wooden boards is often used, and by it water may be carried across depressed points on bridges, such as shown in Fig. 212, a section of the wooden flume of the San Joaquin Co., already referred to. A more elaborate and expensive construction is illustrated in Fig. 213, which shows a concrete canal issuing from a rock tunnel, bored through the mountain, and forming part of the Bosnia development.

An elaborate masonry viaduct is illustrated in Fig. 214, forming part of the Tivoli development, previously illustrated by a general view. This latter case is a good example of the most expensive type of structure, in striking contrast to the tail-race of the

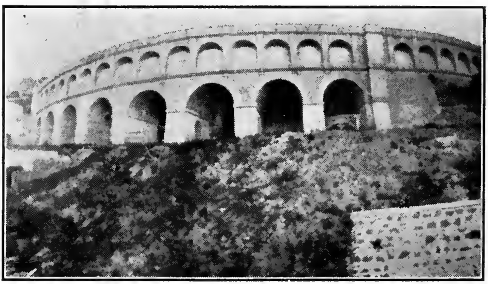

FIG. 214

Susquehanna River development at McCall's Ferry, shown in Fig. 215, which is roughly blasted and left unfinished.

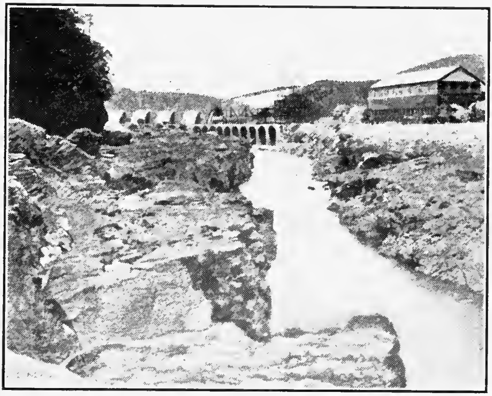

Fig. 215

From the forebay or head-race pipe-lines are run to the lower level, and in Fig. 216 are shown three pipe-lines under construction, connecting with the end of a canal coming out of the woods. Through these pipes will flow water to develop some 5000 h. p., involving part of the development of Lakes Joux and Brenets in Switzerland.

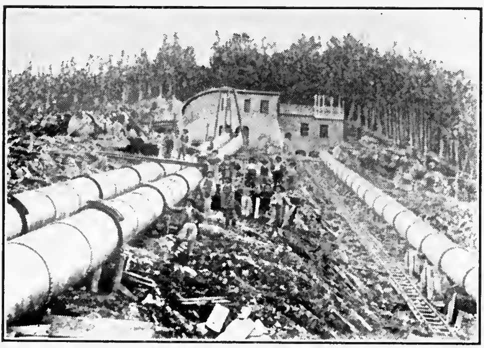

Fig. 216

Where there is a dam on a stream, as has already been noted, it is possible to submerge wheels in the dam, and to illustrate this point there are presented two pictures of the development at Lowell, Kansas, on the Spring River. In the first, Fig. 217, are shown some cross-sections of the dam at various points and in different directions. Section marked *AB* shows controlling gate,

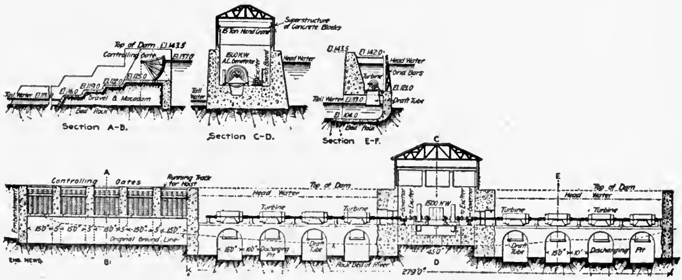

Fig. 217

which is of radial form. *CD* shows power house built inside the dam; section *EF* shows a turbine located in the head-water with its draft tube extending into the tail-water. The long picture at the bottom is a longitudinal section of the dam, showing the location of eight wheels, the power house, and the controlling

Fig. 218

gates for regulating the head. A photograph of the dam in cross-section is shown in Fig. 218 from the down-stream side; the arches just appearing out of the water are the discharges from the turbines located within the masonry structure. At this point the dam is 1250 feet long, and there is a spillway half a mile upstream. The dam is 30 feet high, and with a head of 34 feet 2400 h. p. is developed. In some localities where the head is not very great, especially in the beginning of a long pipe-line, the pipe, instead of being of riveted steel, is made of wooden staves. Such a construction is illustrated in Fig. 219 and is used by the Pioneer Electrical Power Co. of Utah, which transmits electrically to Ogden and Salt Lake City some 10,000 h. p. developed under a head of 450 feet. This water pipe-line is 5 miles long and made of 2-inch Oregon pine held together by $\frac{3}{4}$-inch steel bands, of which 87,000 were used. When the drop in level becomes excessive, the water pipe is replaced by steel pipe running to the lower level. At the end of such a pipe-line is located a power house, just above the tail-waters. The discharge water from the wheels may enter draft-tubes submerged in the tail-water, which case requires the reaction type of wheel, or it may drop off the cir-

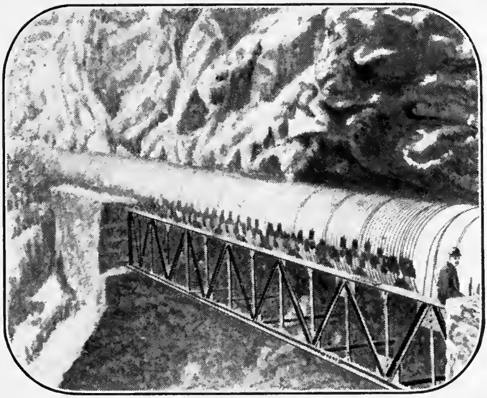

FIG. 219

cumference of open impulse or bucket-wheels such as are used for high heads. The power house of such a high-head development, located just above the tail-

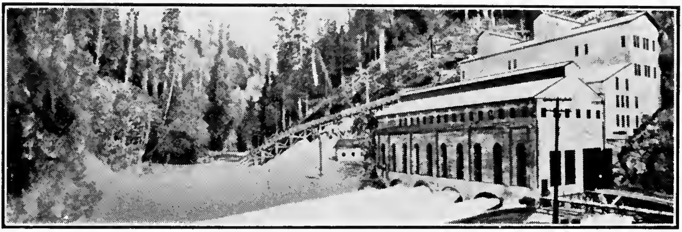

FIG. 220

water, showing the discharge of such bucket-wheels, is shown in Fig. 220. The other construction just mentioned is used in the Canadian-Niagara Power House, at Niagara Falls. The water from the forebay is led vertically downward through pipes set in excavated shafts cut in the rock. Draft tubes from the turbines extend downward into a rock excavation, finally leading to the tail-water. The electrical machinery is carried on the upper-level end of long shafts.

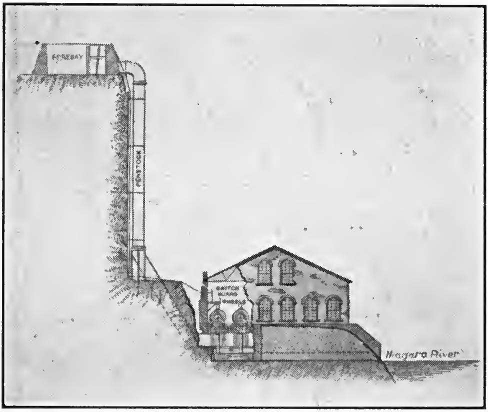

FIG. 221

In this power house the units are each 12,000 h. p.

maximum. Five are installed, and there will be ultimately six more, which will make the capacity something over 100,000 h. p. for the station under a head of 135 feet.

Another arrangement somewhat similar in character and also in use at Niagara is shown in Fig. 221. Here the

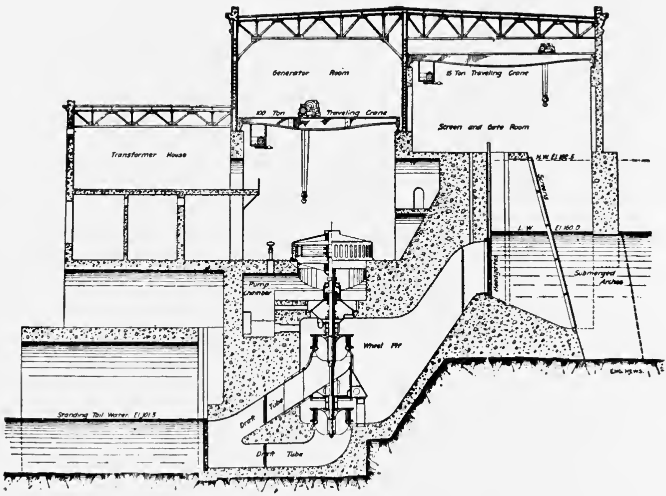

FIG. 222

pipe drops from the forebay vertically for a distance and then inclines, entering the power house. The construction of the power house at McCall's Ferry is shown in Fig. 222 in cross-section, indicating that no pipe-lines at all are used, but that the water from above the dam enters through head-gates and passes through a concrete water conduit, reaching double wheels and discharging through two draft tubes to the tail-water. The method of construction of these concrete draft tubes is shown in Fig. 223 with part of the dam visible in the distance.

From what has been said it can readily be understood why the cost of water-power is so variable a quantity, dependent as it is on the cost of development, which is seldom twice the same. Water-power may

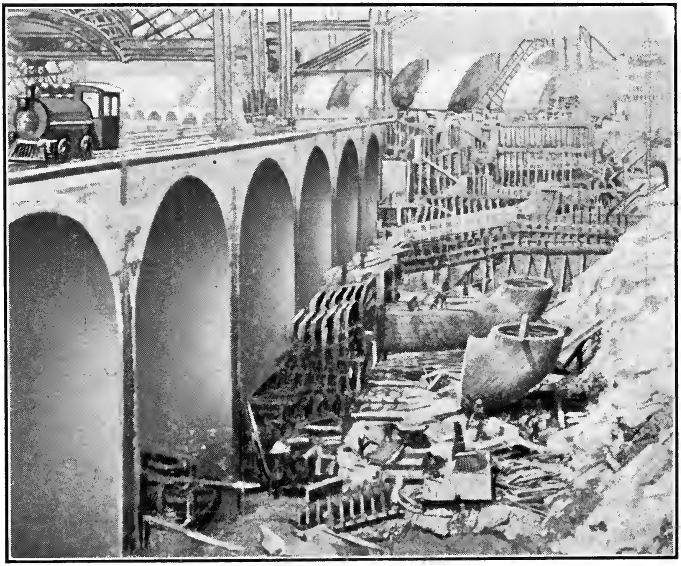

FIG. 223

be the cheapest or the most expensive. When water-power cost per horse-power hour exceeds that of fuel-burning systems, steam, gas, or oil, the development is not warranted, so that a knowledge of the cost of power by these fuel-burning systems for the particular locality in question must be known with reasonable certainty before undertaking any water-power development. Here again is an illustration of the controlling influence of true economy on the engineering methods to be employed in obtaining power, for no matter how clever and ingenious a new scheme, it is warranted only when the cost of the service to be rendered is reduced thereby.

VIII

SOCIAL AND ECONOMIC CONSEQUENCES OF THE SUBSTITUTION OF POWER FOR HAND LABOR

Power is seldom useful at the point where it is generated, because it is never generated for its own sake, but as a means of driving machines to make or do something. These machines must necessarily be scattered more or less, distributed throughout the different floors of one building, or located in each of a number of buildings forming part of the same establishment. In fact, one power-generating system may supply motive power to the machines of shops, factories, or railways extending over hundreds of miles of country. The object is to drive these machines and drive them as economically as possible, and as there is no other reason for utilizing nature's energy, without machines to drive or work to be done there would be no power systems. From the commercial or industrial standpoint the power-generating equipment cannot be considered by itself, but only in association with some means of transmitting the power from that place where it is most convenient to generate it to that place where it is most convenient to use it. These power transmission systems take a great variety of form, but may be grouped into three classes for the purpose of review. The first will include direct push or pull by mechanical elements; the second push by fluids under pressure with or without expansion; and the third all systems not dependent on push or pull, but involving a transformation of energy from a form not easily transmitted to another that is. When the distance is short, the direct push of the teeth of wheels or gearing may be used. At a little greater distance between driving and driven points chains running on toothed wheels, or belts of leather, canvas, or steel, running on smooth wheels or pulleys, will transmit a force by a direct pull from the circumference of the driving to that of the driven wheel. In these cases, however, the two shafts must be at not too great distances. Still greater distance between driven and driving shafts, more especially when they are not in line, or where the transmission must take place around corners of buildings, has led to the substitution of ropes running in grooved wheels, constituting the rope drive, and available for distances approximating a thousand feet. Gears, chains, belts, and ropes are all means of transmitting power from one rotating shaft to another through short distances by the actual transmission of a force by push or pull at some properly designed part. When the distances become greater than it is safe to run ropes, then the second system becomes available by substituting the pressure push of fluids in pipes. When the fluid is non-compressible, such as water, there is no further action than by the push, but the use of air permits of additional work by expansion. If an engine be arranged to drive a pump, all its energy may be consumed in pushing water against a certain pressure and at a certain rate through pipes that may be of any size or shape or length; and allowing for a loss in pressure by friction through these pipes, the water may exert a corresponding push on any point of the hydraulic main and be there used to operate the pistons of hydraulic engines. Thus, by the addition to the engine of a pump, an hydraulic motor, and a water-pipe connecting them, the engine power may be transmitted almost any distance and in any direction. Such an hydraulic system of transmission is in use in the city of London, where there are high-pressure water-pipes running through the streets, supplied from a central station, and delivering water to hydraulic elevators and motors. Of course, the farther the water is transmitted the greater will be the cost of pipe and the greater will be the loss in energy by friction and leakage; so that at some distance the cost of power, which is continually increasing each foot from the engine, will become greater than the cost to generate directly by a competing system, and there the value of the transmission system ceases. If, instead of the pump, an air compressor be driven by the main engine, the compressed air delivered to pipes may be made to flow through the piping system to any distance desired, and from any point it may enter a compressed air-engine, similar in all respects to a steam-engine, and there do work by direct push and by its expansion in addition. As already explained, the steam-engine does work most economically when a little bit of high-pressure fluid is admitted to a cylinder, cut off, and the isolated charge expanded to the terminal pressure. Substituting air for steam, the action would be the same. As a consequence, each cubic foot of high-pressure air can do ever so much more work than a cubic foot of water at the same pressure, and as a consequence, a pipe of a given size can transmit more power in the form of compressed air than in the form of water. Compressed air transmission systems are very much more common because they may be made more economical than hydraulic systems so far as the pipe-line is concerned. They are used extensively about shops and mines, the air being pumped into the mine to operate drills, hoists, and sometimes pumps as well, the exhaust from the machine also helping to keep the air pure for breathing and assisting the ventilation. In the streets of Paris there are laid compressed air mains for transmitting power in this form from a central station to users scattered throughout the town. Even the compressed air system, which is better adapted to long distances than the others examined, is limited to a few miles so far as economical transmission of power is concerned. When really long distances are to be covered, then the third method noted, that of change of energy form, is still available. In fact, some of the systems of this class are found to be even better for the short distances than those systems that are limited to the short distance. There are two systems in this class: one transforms shaft power into electric energy which flows over wires, and the other transforms the fuel into the gaseous form and transmits it through pipes; this latter is as yet not much used.

The most commonly used power transmission system to-day is the electric, and this is employed for all distances up to and even exceeding one hundred miles. In many cases it is found economical even within the limits of a single factory building to transform the shaft power directly into electric energy, transmitting this over wires to electric motors located directly on each machine requiring power. Of course, each transformation and each foot of transmission involves a loss of energy, and the studying out of the conditions fixing the economical limit of distance for any system is one of the nice and difficult engineering problems of the day.

The fundamental ideas underlying the electric transmission of power are very simple, but the details of most economic execution are extremely complicated. Nearly every one knows what a magnet is, and something of the flow of electric current over wires to ring bells and operate telegraph, telephone, and electric lights; but not so many know of the relation between a magnet and an electric current flowing on wires. The discovery of this relation was one of the greatest in point of scientific and commercial value that the world has ever seen. Faraday found, about the year 1832, that when a wire is moved in the neighborhood of a magnet an electric current will flow through the wire and it will take some pushing to accomplish the movement. Now dynamos or electric generators are nothing more than well-designed magnets, past which many wires can be pushed mechanically and in an orderly manner. Each individual wire as it passes the magnet has a current of electricity set up in it, starting from zero as it approaches, later rising to a maximum, and finally falling to zero again as it leaves the magnet. Many wires passing rapidly in succession may be made, by suitable mechanism, to contribute each its share of electric current and all these small currents added up, or accumulated in one, constitute the output of the generator. The way in which the adding up is done differs in different types of generators and constitutes the difference between them. Now, this same current which was generated by driving wires across the faces of magnets will, if led to one or more wires near the face of other magnets, result in the reverse operation. As soon as the current flows through one wire the wire will push itself with respect to the magnet, and many wires fastened on a drum will cause that drum to rotate. This is the basal principle of the electric motor, which like the dynamo consists of bundles of wires carried on drums, disks, or wheels of suitable sort, and a system of magnets. In the case of the generator the wires are pushed past the magnet by the engine power and a current generated. In the case of the motor the current is led through the wires and a push results, which may be made continuous rotary motion. It is somewhat curious that this double or reciprocal action between the wires and the magnets was not recognized at the same time. While the principle of current generation was discovered in 1832, it was not until 1873, or forty-one years later, that the reciprocal action was found, making it possible to operate a motor from a generator any distance away, and through the double transformation of energy transmit the power of the prime mover or engine proper. Long distance transmission was accompanied by great losses with the sort of electric current first generated, and it was not until the discovery that a current of very high voltage or pressure could be transmitted with much less loss, that economical long distance transmission became possible. The economic and safe application of this idea involved the design of additional apparatus, called transformers, for changing the pressure of a current, or even one kind of current into another, so that a generator might be built to make any kind of current at any convenient pressure which could be transformed to high pressure for transmission, and near the motor be again changed to a pressure or kind adapted to the most convenient or suitable kind of electric motor. The first practical high tension long distance transmission system of this kind was not installed until 1893, only seventeen years ago, at Great Barrington, Massachusetts, whereas to-day it would be practically impossible to make a list of the electric transmission installations, so numerous have they become.

When gas is generated in gas producers, as explained, it is possible to conduct that gas through pipes to engines located at a distance, so that the transmission of gas in pipes to gas-engines really constitutes a power-transmission system, the most recent of the methods now under consideration. It is so far but little used in this country, although it has been applied to factories in Germany, where a gas producer located at a most convenient point for the receipt of coal makes gas for transmission to ten or a dozen factory buildings scattered over many acres, each with its own gas-engine; the same gas is also available for the operation of industrial gas furnaces and with suitable mantles the generation of factory light.

We have seen that there are three systems of power generation, the steam, gas, and water systems, and a great variety of means of transmission; so that the decision as to which form of natural energy to use, whether fuel or water, and by which system to transform it into work and to transmit the energy developed to the machines requiring it, is a problem of great complexity having two distinct phases, one strictly scientific and the other commercial, the two together constituting one branch of engineering practice, and constituting one of the first and most fundamental steps in the carrying out of any industrial problem of manufacture or transportation. That system of generation, transmission, and application of power to any machine requiring power that is best for the particular case is the one that will perform the required duty for the lowest cost; and in the determination of the best, general rules are of comparatively little use. Each case must be studied by suitably qualified experts, and all the data collected on the different possible and satisfactory ways, with the cost of each, must be compared, before a judgment can be reached; and it seldom happens that all the systems or methods are equally suitable or that the most suitable is cheapest. The judgment must, therefore, involve a weighing of cost against relative suitability. For example, cars and trains may be moved by steam locomotives or by electric motors supplied from a central station. It has been found that in the streets of cities the steam system cannot compete either in cost or suitability of service with the electric, while on transcontinental or trunk lines the steam is so far superior in point of cost, though the electric would be equally suitable. Cases intermediate between the congested and dense city traffic and the long haul with light traffic present a most difficult problem of the weighing of suitability and cost, and one that is to-day agitating practically every railroad the world over, but without as yet any generally accepted solution. Similarly, the driving of machines in a factory offers a parallel controversial case, for they may be driven by belts from a central plant or by electric motors supplied by engine-driven electric generators. In some cases the electric system has proved its unquestioned superiority, in others the belts are better; but in the great majority of cases there is a lack of concerted opinion, even though relative costs and suitability have been much studied and the data tabulated and published.

With regard to generation itself the situation is equally complex; in most cases there may be just controversy and difference of opinion, while in others the proper course to pursue is clear. For example, when the work to be done is continuous and the average load near the maximum power capacity of the plant, the fuel and labor costs are high in proportion to investment charges, and very expensive machinery is warranted if it can save ever so little in the fuel charges. This is the case with most municipal water-supply pumping stations. On the contrary, if the average power demand is very small in proportion to the maximum, then for a large part of the time the machinery is idle, and the investment charge per unit of power generated becomes high in proportion to the fuel, and only cheap machinery is warranted even if the fuel cost is high. Such is the case with farm engines which may work at full load only a month or two in the year. Again, if fuel is very cheap, as at the mines, where it seldom exceeds eighty cents per ton, it would not be good practice to use expensive equipment to save fuel; while in countries like Mexico and South America, where coal often reaches $12 per ton, almost any expense in machinery would be warranted to make the coal go as far as possible.

It can be said that there is only one best way for each case, but an almost infinite variety of cases, and the amount of time and study to be expended in finding the best that may be justly warranted must be based on the saving that might be effected by selecting the best over the worst; for if a preliminary examination showed four different systems to be equally suitable and nearly equal in cost, it would not pay to bother much with working out the exact details of each, when any one would do. The most elaborate study is warranted only when the possible ranges of cost are great, or, and most often, when the cheapest is not as equally suitable as the most costly.

After all, we are all not so much concerned with the ways in which power may be generated for its own sake, or even the relative value of the ways it may be transmitted and applied to the machinery of manufacture and transportation, as we are with the bigger industrial problem of daily supply of the world with the means for comfortable living. From what has been said concerning the complexity of the power problem, it may be easily inferred that this larger question, by reason of the greater number of things that enter into it, is ever so much more complex and must be approached with great caution if one would avoid drawing unwarranted conclusions. However complex or big a question may seem, it can by patient study and analysis be resolved into simple terms, and guiding principles be evolved that are useful. While, to be sure, there will always be certain questions left ever unsolved, and hence of controversial nature, yet the fact that out of the chaos some order has been evolved proves the effort is worth while and leads to a belief that continued study along sound scientific and logical lines will finally resolve the rest.

It has been said that by the introduction of power-driven machinery the modes of life, habits, comforts, and pleasures of the great mass of the people were greatly changed; so much so as to lead historians to characterize the movement as the industrial revolution, meaning thereby not only that industrial methods were revolutionized, but the whole world, by means of and as a result of these industrial changes, all of which started with the use of power-driven machinery when James Watt applied his steam-engine to the driving of textile mills in England one hundred and sixty years ago.

This industrial change was briefly reviewed in the first lecture of this series; the magnitude of the modern industries which did not exist before the time noted was pointed out, as well as the ever increasing proportion of the population directly dependent on them for wages and salaries; the equally large number of traders or merchants supplying raw material and distributing manufactured products of ever changing form from the same natural substances that have always existed since the world began; the absolute dependence of all of us on the manufactures and the transportation systems for all that we need and much that we do, and the importance to all of at least trying to understand how it all has happened. With such world questions before us, why, then, has so much time been spent in discussing the construction of steam-boilers, gas producers, vaporizers, engines, turbines, nozzles, and valves, and in studying the principles of gasification and combustion of fuel, generation and expansion of steam, or the flow of water, when instead attention might have been directed to the more popular questions of industrial growth itself, its effects on the organization of society, the creation and distribution of wealth, or the government of the people? Because these questions, of infinite complexity compared to the economic generation and application of power to machines, have been much discussed by economists, sociologists, historians, and statesmen, while the power question, which is so large a factor and so strong a formative force, has never been presented to a popular audience; and finally, but by no means least, because it is the finest possible example of the value of patient, logical, scientific study, in resolving complexity into comparative simplicity, yielding to exposition, and serving as a model of the method to be applied to the apparently more complex and larger questions. Place before the average man a collection of all the standard power-generating machinery, and it would not be too much to say that he would at once admit its explanation and creation to be far more difficult for him to discuss than a question of politics, government, or economics, on all of which he has some well-defined opinions, and yet all of these are far more difficult to solve than any machinery problem; how much more cautious, then, should we be in reaching conclusions, and how much more needed is a method of procedure that is safe and sane. Who could have foreseen the tremendous effects of studying wheels, cylinders, rods, and chambers, and the designing of these to carry out the physical processes of rendering available for man's use nature's energy to change into useful and more serviceable forms the substances of sea, farm, forest, and mine? Probably no one. It is not surprising, then, that the average man has a feeling that there is no connection between his needs and pleasures, his commercial or social standing, his opinion or mode of thinking, and the dirty shop, the hot and mysterious engine room, the laws of thermodynamics and hydraulics, and their application to machine structures, or any other part of the problem of power generation and its application to manufacture and transportation. Yet there is a twofold connection, for without these things the world would not be what it is to-day, and the methods and principles involved in the creation of the machinery have revealed Nature herself, and are equally applicable to the other problems that seem of more intimate importance. No man can afford to fail to inquire into all that concerns his welfare, more especially those things that may serve to guide his thinking, which controls action; yet it is all too true that not only has the study of industrial development and its effects been neglected by the public in general, but the work and methods of the scientific mechanical engineer, who is responsible for it, are practically unknown.

So far attention has been directed mainly to the work of the engineer in developing the machinery of power; but the machinery to be driven is of equal, if not greater, importance, and while time will not permit us here to examine the principles and apparatus of the manufacture of all the articles of common use, it would be decidedly worth while to do so. Precisely the same methods are, however, applied as have been reviewed in the discussion of the power machinery, and it is hoped that what has been said will serve to arouse interest enough to induce a few to take up some reading on this phase of the subject.

All the time that the engineer of the industries has been creating or applying machinery for the most economic use of nature's energy and of the common substances used in manufacture, he has had to meet constantly the parallel problem of making the best use of the effort of man himself in the production of results, for results are obtained, not by power alone, by machinery alone, by men alone, but by all working together. It is, therefore, just as much the duty of the engineer, who began by studying nature's substances and forces, to study also the forces controlling men, so that each individual may contribute the best that is in him, just as in the case of an engine itself. This parallel study of the most economic use of man's own efforts has been placed on a scientific basis only in recent years, and from present indications is destined to receive as much painstaking analysis in the future as it has lacked in the past, which lack was the cause of much disorder, misery, abuse, and social unrest in the early days of industrial expansion. With a brief, but necessarily hopelessly inadequate, review of some of these social and economic changes, to round out the subject, we shall close this series.

In the old days, and by the old days we shall understand the days before the steam-engine and the machine method of manufacturing which it made possible, the people could be divided into classes somewhat as follows. The first class would include all those who produced everything they needed, and this would be the largest class of all, constituting the bulk of the population, the farmer or domestic manufacturing group. The materials for food, clothing, housing, heating, and lighting were all produced on the spot by the man and his family, with perhaps a few helpers. It was unnecessary to buy anything except the luxuries, and few of these were indulged in by this class. Being independent of their neighbors, there was no particular necessity for travel, so that there were few towns, and these were small. Occasional gatherings at fairs were held largely for pleasure, but partly for trade, which consisted mostly in exchange of horses, cows, or wool, or whatever one man had in excess for that of which he was a little short. In the second class there would be grouped those people who produced nothing at all, — the soldier, policeman, preacher, and government officer. These bought everything they needed, to supply which a little transportation was maintained, carried on by wagons, sailing vessels, or canal-boats. This class constituted the principal town population, together with those few traders who served as middlemen between the producer and the non-producing consumer. The third class would include those people who produced some of the things they needed and bought the rest, such as he who set up a few hand-looms in a village and bought wool, making cloth for himself and selling it to others. In some cases the farmer would also be included in this class, when, for example, he bought a wagon or cloth. The fourth class would include those who produced all the time for others, but made practically nothing that they needed themselves, devoting their time to the creation of things for others, which they sold and from the returns of which they bought what they needed. This would include the ship-builders, who never sailed a ship that they built, the tailor, who spent all his time in making clothes for other people, the iron maker, carpenter, mason, shoemaker, jeweler, and the armorer. The size of this class, which consisted partly of wage-earners and partly of master workmen, who were also traders, was comparatively small, being limited by the size of the class that could afford to buy their services. The really large class was the farmer or agricultural group.

When the power-loom and spinning-machines were produced and the steam-engine put to work to drive them, the whole condition of affairs changed; and following the same analysis there was an enormous increase in the wage-earning group, the last-mentioned producing class, with a corresponding decrease in the farmer or domestic manufacture class. More and more people came to work in the factory, because it could produce cloth far cheaper than it could be made by hand spinning and hand-looms in isolated homes in the country. Every such factory worker became a producer of goods that he did not use himself except in a very small degree; and as factories increased in numbers the factory system displaced the domestic system of production not only in cloth, but in all things. This continuously producing class of factory workers, drawing on the independent farmer class, decreased the number of self-contained individual families, and thus was set up what amounts to practically a new organization of society, as a result of what has come to be known as the factory system. The concentration of workers around a factory created a town or enlarged an existing town. The presence of many workers stimulated the location of another factory there. Thus factory followed factory, town population continuously increased, and the farm population decreased. In this way is the growth of the city traced to the factory and back to the steam-engine or power plant as the prime factor in its creation. This same concentration of population in cities producing practically anything that was needed stimulated a corresponding increase in the trading class. The factory worker did not produce his food any more, but had to buy it. So the grocery store and butcher shop increased in numbers enormously, and being located in the cities to supply city workers, their owners and clerks in turn increased the population of the city and drew still more from the farms.

All farm productions as well as those of the mine and the sea had now to be transported to these cities to feed the factory workers and the tradesmen and to keep them supplied. Thus was transportation stimulated, stimulated to a degree that ultimately demanded the creation of the locomotive and steamboat. Transportation was also stimulated in another direction, for not only were the food and other necessities for the city population to be brought from a distance, but likewise the raw materials for the factory, which had a capacity in a short time far exceeding that of the surrounding country to supply. Ships and railroads were put to work to bring these raw materials from all over the earth, to keep the factory supplied, and it was cheaper to do this than to continue the domestic manufacture near the place where the raw material was produced. It must have been cheaper or it never would have been done. Having drawn the raw material from all over the earth to the factories for manufacture, there was necessary a reciprocal transfer or transportation system, because the manufactured article was produced in quantities exceeding the capacity of the immediately surrounding country and town to use. England produced cloth for the whole world, as well as many other things, for it was in England that these changes took place originally and developed most rapidly. It is easy to see by such analysis as this how the simple act of driving machines by engines for the doing of work formerly done by hand created the city, increased the trading class, stimulated transportation to a degree only satisfied by the application of the same steam-engine that created the factory, and the transportation demand to the movement of the car or boat.

There were other effects, however, as important and far-reaching as these, and necessary accompaniments or consequences. This transportation to and from factories and all parts of the earth was the beginning of the modern world commerce, the enormous increase in the class of wholesale dealer of manufactured commodities and raw materials, as well as in the class of retail storekeeper in every town of the land, to supply that which the factory made so much better and cheaper than it could have been produced before, or that which the factory made which had never been heard of before. To buy a ship-load of raw material, transport it across the ocean in ships that might take months in transporting, required the tying up of large sums of money, and this could be done only by him who had the money. Similarly, the buying of a ship-load of manufactured goods to be sent from England to China likewise required capital, for during all the period between purchase and sale a large sum of money or its equivalent in value is idle, and the act can be accomplished only by the possession of capital. The manufacturer, between the time of purchase of raw material and the time of sale of manufactured product, has given out money for which there is no return. Not only has he paid out money, which might be thus tied up for months or even years in the material itself, but he must continually pay workmen through this whole period of time, they demanding their pay every day or every week regularly. There is likewise required capital sufficient to maintain operation between the period of wholesale purchase of manufactured goods and their retail sale. Even before the factory can be started, great buildings must be erected and enormous sums of money sunk in the filling of them with machinery. This likewise required capital. No one could manufacture and no one could carry on the world's commerce who had not capital. Now, in the days when these movements started, there was practically no use for capital, that is to say, comparatively. The only rich people were the landowners or those who had been landowners, or descended from them, and whose accumulation of wealth had been derived largely from farm rentals. The manufacturing era offered to those who had capital an outlet, and no one could engage in the business who did not have the capital, and he who had the capital and used it in this way could expect returns for his money and make a profit and thus accumulate more. So there was a tendency established, continuing to our present day, toward the concentration of wealth, sometimes described as the "rise of capitalism," traceable directly to the use of power-driven machinery more than any other single thing. It frequently happened that periods of hard times appeared. The farms did not yield their crops, and the purchase of everything decreased. The new manufacturer produced standard goods far in advance of real demand or without regard to any known demand, contrary to the old domestic worker who made a shoe only when somebody asked for it, and then made it to fit a particular foot. These periods of business depression, now so called, found the manufacturer with large sums of money tied up in unsold goods, which had been made up only on a hope that they could be sold, but which he was sure he could sell perhaps the next year. He, therefore, did not want to stop his factory, but manufactured for stock, to be able to supply the retarded demand when it came and to keep his skilled workmen busy. He might decrease the output, but it must be kept going. He must pay wages all this time to his workmen, so he had to borrow money on the goods he possessed, as security. Thus was established the modern system of industrial banking, the borrowing and loaning of money in vast sums to keep industrial enterprises going between periods of purchase of stock and sale of product.

The factory owner, besides being a buyer of raw materials and seller of manufactured product and owner of factory with its machinery, was an employer of labor, labor of all sorts from the most unskilled and ignorant to the most skilled physically, or the most highly developed mentally, of course, in different proportions for the different classes. These factory workers constituted a large class of the community and were themselves divided into classes. There was a man skilled in firing boilers, a man skilled in taking care of the engines, other men skilled in maintaining the machines and repairing them, others skilled in operating any one machine, still others engaged in buying for the factory, more in selling, and still others in conducting correspondence and keeping records of costs, in paying wages, in negotiating with banks for funds, others in inventing new improvements. This assignment of special duties to each individual is known as the division of labor, and while the system created opportunities for advancement to higher grades requiring more skill, better mental equipment, or concentration of effort n those fitted by nature or education to advance, it had also the effect of clearly marking off the unfit, and in some cases tended to keep them unfit. For when a man has learned to do only one thing, and is worked too hard at it, he is too tired to learn to do something more difficult and stays in his class. It appears from the old books on the subject that this latter condition was most common, and that the unskilled were much abused, and had a very hard time. The workers, having learned to do one thing for wages, were dependent for their living on the wages they could earn, for from these wages everything they needed had to be bought, and they could not advance unless they learned to do something more difficult, but with ever increasing competition among themselves, because there was less and less of the skilled work to be done. The factory owner, to get as much product from his machinery per day as possible, increased the working day, and cases are on record noting a working day of sixteen hours, which was so exhausting as to kill ambition and study. The factory owners also established kitchens to feed their own people, and in some cases they erected cottages to keep them near by, thus putting them more and more in the power of the factory owner, who, when unscrupulous, could feed them badly, clothe them badly, make them work in poorly lighted rooms without sanitary conditions, seriously injuring their health and taking from them all the pleasures of life and prospects for betterment. The performing of the manufacturing operations by machines divided the total number of operations into a large number of steps, some of them machine steps and some of them hand steps. Some of these things that had to be done were very simple, so simple that a child could do them; and the desire of the factory owner to get each operation done as cheaply as possible led him to employ children to do those things that they could do, and women to do other things. These women and children had no more pleasures, no shorter hours, no more sanitary surroundings than the men. For a time the conditions of these factory workers seem to have been most miserable; then began a reaction, the reaction for adjustment of conditions extending in one form or another to our present time, which adjustment took place partly by force and partly by intelligent coöperation.

For a long time nothing but force was used, and probably it was the best way; it began with philanthropic agitation and labor unions directed toward reform through legislation, and the statute books of practically all industrial nations contain acts controlling the hours of labor, restricting the employment of women and children, requiring the maintenance of sanitary, healthful surroundings in the workrooms, and in some places providing for accident compensation or employees' pensions. At the present time a new attitude toward these questions is beginning to take root, involving a reduction of appeal to force and the substitution of coöperation; but from the time that the evil conditions began to be noticed almost up to the present we find a condition of industrial warfare, workman against employer, labor against capital. For a long time this condition was believed to be absolutely necessary because it seemed clear that the two interests were opposed, and on this ground all sorts of movements were organized, practically all involving the assertion of right based on might, that is, up to recent times. It must be understood that these conflicts were not confined to the manufacturing industries, even though these were responsible to so large a degree for the sharp drawing of the lines of division between the two classes. As a matter of fact, much of the most bitter of this sort of war was fought outside of the ranks of what might be called the machine industries, and it is a most significant fact that these particular industries are to-day pointing the way toward a betterment of conditions that shall be permanent, and that shall involve right and not might. In these machine industries, where the study of nature's processes, forces, energy, and substances has resulted in so much undoubted good for all, similar study of man-controlling forces is meeting with equal success. It is sometimes stated that the evil conditions that came with the creation of the factory system, in times when society was not organized to apply a remedy and avoid abuses of the new found forces, are responsible for the creation of the trade-unions, but this is not the case any more than the assumption that labor abuses did not exist before the factory system. The trade-union, as a matter of fact, while it played an important part in the change of these conditions, was not a creation or product of the factory system, as the following quotation from the "History of Trade Unionism," by Sidney and Beatrice Webb, will show: "It is often assumed that the divorce of the manual worker from the ownership of the means of production resulted from the introduction of machinery, and the factory system was responsible for the trade-unions. Had this been the case we should not, upon our hypothesis, have expected to find trade-unions at an earlier date than factories, or in industries untransformed by machinery. The fact that the earliest combinations of wage-earners in England precede the factory system by half a century and occur in trades carried on exclusively by hand labor, reminds us that the creation of a class of lifelong wage-earners came about in more than one way." For example, the master tailors. "The master tailors in 1720 complained to Parliament that the journeyman tailors about the cities of London and Westminster, to the number of 7000 and upward, have lately entered into a combination to raise their wages and leave off working an hour sooner than they used to do." "It is easy to understand how the massing together in factories of regiments of men all engaged in the same trade, facilitated and promoted the formation of journeymen's trade societies, but with the cotton spinners, as with the tailors, the rise of permanent trade combination is to be ascribed in a final analysis to the definite separation between the functions of the capitalist and the manual worker, that is to say, the direction of industrial operations and their execution. Only in those industries in which the worker has ceased to be concerned in the profit of buying and selling can effective and stable trade organizations be established." "It appears to us from these facts that trade-unionism would have been a feature of English industry even without the factory system."

Just what part trade-unionism played in the attack on these factory abuses is not quite clear, but that there were vigorous attacks and that there were real abuses, there can be no doubt. As an illustration concerning the older feelings on this subject, note the following quotation from a little book, written in 1836 by P.

Gaskell, entitled "Artisan and Machinery": "It would have been well if steam and mechanism, in breaking up a healthy, contented and moral body of laborers, had provided another body, possessing the same excellent qualities as men and citizens, but it has not been so." This is offered, not as representing anything that is now true, but as an indication of the feeling at the time of writing, 1836, concerning these abuses. Even John Ruskin, whose literary productions have met with admiration among those capable of judging, blamed the mechanical inventions and industrial progress for about everything that he noticed wrong in the organization of society.

Abuses of the laboring classes as well as the divorce of the functions of capitalist and manual worker existed in other industries before the factory era, and it is well known that even at the time when this began coal was being carried from English mines on the backs of women. As a matter of fact, it is in the factory management of labor and machinery to-day that this most perplexing source of social unrest is being gradually solved; and the solution will be based on the general acceptance of that most fundamental proposition, that the interests of worker and capitalist employer are not only not diametrically opposed, but absolutely identical, all of which appears more clearly when it is realized that the wealth of the world is not a fixed quantity, and that he who gains does not necessarily take from another who loses. We may assume that wealth is anything that somebody wants, or its equivalent in the means to secure it. Now the very act of manufacturing makes something new out of something old, makes something useful out of a useless thing, or makes from something that nobody wants something that somebody does want, or from something of value something of greater value in point of desire to possess it. Often the new article is something never heard of before, but which is wanted as soon as seen, witness the automobile, the electric light, the gas cook-stove, or the rubber boot. From this point of view, not only is the product of the farm, sea, forest, or mine wealth, but the operation of every manufacturing machine in the land is most positively a wealth-producing process. The last census report showed an increase in money value of nearly 80 per cent by the manufacturing operations on the raw material. So also is transportation. The rubber that grows on the banks of the Amazon is just about useless to the natives. It is, however, a very much-desired and high-priced article here. Traveling through the country will show every fall thousands of barrels of apples lying on the ground rotting, while apples in town bring a good price, which indicates how much they are wanted. That which is wanted in one place may perhaps be quite useless in another. The application of machinery to transportation and manufacture has, then, been a great wealth producer, and trade and commerce may likewise be so regarded from this point of view. However, the more primary, the more direct of the two, as wealth producers, are the manufacturing processes rather than transportation or commerce. Having produced something useful, or in more desirable form, from something less desirable, the manufacturer finds it possible to secure a profit for his skill, skill in carrying out the operations required for the transformation of substances, skill in gathering money necessary to carry on the work, skill in managing men, in buying and selling. On the other hand, the worker has only his time and special skill of hand or brain to offer for service with the capital and other sort of skill of the employer; together they produce wealth which may be shared to the profit of both, in proportion to the contribution of each, without taking anything from anybody else. Of course, if either party tries to take the whole gain, the other may not be criticized for fighting for his share, no matter which one it is. Now, the share of the worker is represented by his wages, and the share of the employer by his profits; if either takes more than he should, the public that buys the product pays the bill. It is to the interest of the public as a whole, therefore, to know something of this sharing problem, one phase of which is the effort of the worker to secure more and more wages regardless of work done, and the other that of the manufacturer to get as much for his product as he can after paying the wage demand and for material and the capital and skill used in management. Competition is often considered a sufficient force to regulate the prices of manufactured goods, while the fixing of wages and salaries, being subject to no such automatic principle, has been, and is yet, a bone of contention. Intelligent study of this problem by engineers of great breadth is, however, producing effects, and it is interesting to note that greater progress is being made in the industries in which machinery plays an important part, and in this country more than in any other. In the industrial history yet to be written, engineers like Taylor, Gannt, and Emerson, whose philosophic studies of the problem are producing practical results that are now recognized, will rank with Watt and Arkwright as benefactors, pioneers in the movement to minimize waste of labor by proper systems of compensation and management, as has already been done by the substitution of machine-work for so much of hand labor. Nothing but good can result from the most efficient use of nature's materials, nature's energy, and the power derived from it, and last, but not least, the most efficient use of man's own effort and ability. More can be done and is now being done for the general good in the minimizing of labor waste by trained engineers to-day, with a corresponding increase of industrial peace and social welfare, than has been done in almost a century of legislation, or by the teachings of economists and sociologists of the old school.

Few beside those who have studied the question have any idea of the enormity of labor waste to-day, and, therefore, of how much less things might cost than they do, and of how much higher wages might be paid without reducing profits, and in spite of reduction of prices. All modern scientific profit-sharing and fair wage-systems are, however, based on the study of these things. Mr. Harrington Emerson tells of a shop in Cincinnati where a certain part of a machine had been made regularly by good men in thirty-four hours, and it was claimed by the workmen that this was a fair and proper time. By offering inducements that time was changed, and the same work is now done regularly in ten hours. A similar case was reported by Mr. Fred W. Taylor, at the Bethlehem Steel Co., some years ago, where laborers loading pig-iron on cars averaged about 12 tons per day, but after inducements were offered this was increased to 45 tons per day. Another case, reported by him at the Midvale Steel Co., showed that the turning or finishing of certain large forgings was done at the rate of four or five pieces per day, which was increased to ten pieces per day without serious tax after the men were induced to try. One of the most earnest and practical engineers studying this problem and applying remedies is Mr. H. L. Gannt, and we cannot do better than quote his summary of the situation from some lectures delivered on the subject before the students of Mechanical Engineering at Columbia University.

"In any discussion on the relations between employer and employed we must recognize the fact that in the majority of cases men still act on the principle that 'they should take who have the power, and they should keep who can.' As long as the interests of the employer and employed seem antagonistic, there will be conflict, and in any discussion of the subject we must recognize that antagonism means conflict. Until we can find some means of doing away with the antagonism, the conflict will continue.

"If the amount of wealth in the world were fixed, the struggle for the possession of that wealth would necessarily cause antagonism; but, inasmuch as the amount of wealth is not fixed, but constantly increasing, the fact that one man has become wealthy does not necessarily mean that some one else has become poorer, but may mean quite the reverse, especially if the first is a producer of wealth. The production of wealth can be so greatly facilitated by the coöperation of employer and employed that it would seem that if the new wealth were distributed in a manner that had in it even the elements of equity, neither party could afford to have the working arrangement disturbed.

"As long, however, as one party, no matter which, tries to get all it can of the new wealth, regardless of the rights of the other, conflicts will continue.

"It is undeniable that unions have advanced the cause of workmen in general, and we must not blame them for using force to accomplish their ends. It was the only means they had. If we wish them to use any other means, we must provide them with a means that they will consider more desirable, and that will give better results, for in this country so long as a man conforms to the laws of the state, he has a right to govern his actions in such a manner as his interests seem to dictate. Men join the union because they think they will be better off in the long run for being in the union. The idea of the union is to get a higher rate of wages for the whole class, because in general nobody in that class can get a substantially higher rate unless the whole class gets a higher rate.

"The employer generally pays but one rate of wages to one class of workmen, because, as a rule, he has no means of gauging the amount of work each man does.

"Under ordinary conditions, where there is no union, the class wage is practically gauged by the wages the poor workman will accept, and the good workman soon becomes discouraged and sets his pace by that of his less efficient neighbor.

"Increase of efficiency is essentially a problem of the manager, and the amount to which efficiency can be increased by proper management is so great in most cases as to be almost incredible.

"There are only two methods of paying for work. One is for the time the man spends on the work, and the other is for the amount of work he does. The first is day-work. The second is piece-work. All other systems, whatever may be their names, are combinations of these two elementary methods in different proportions. It is natural that the employer should wish to get all the work he can for the money he spends. It is also natural that the workman should wish to get all the money he can for the time he spends. Any other condition would be wrong, would be almost suicidal. These two conditions seem to be so antagonistic that most people give up any attempt to harmonize them and adopt a scheme of bargaining. Under such a system the most aggressive group or the one that has the most favorable conditions wins in the long run.

"Day-work is of two classes: first, ordinary day-work, in which there is no attempt to get individual records and every man of a class receives the same wages, regardless of the amount of work he does; the second, that in which the work is carefully planned beforehand so each man can have continuous work, and so that an exact record can be kept of what he does and his rate of pay adjusted accordingly.

"The first method leads the good men to organize a union. In the second class of day-work some intelligent man studies the work to be done, lays it out carefully, provides the proper appliances, divides it up in such a manner that it can be done by individuals or by small gangs, so that an exact record can be kept of what each individual or gang does and compensation paid accordingly. Such a method of handling workmen has exactly the reverse effect, and their efficiency begins to increase at once. When we increase one man's wages because his record shows he deserves it, it not only does not cause trouble with the other workmen, but it acts as a stimulus to them. To carry out this plan there must, however, be created a system of training men and teaching them the most efficient way to get the work done.

"If, then, you train a man to be efficient and adopt a system of management which enables him to utilize all of his energies in productive work, you can afford to pay him far higher wages than he can get where the workmen are not trained, and where the system of management is not such as will enable him to work continuously and efficiently.

"If you keep an exact record of what each worker does, surround the men with conditions under which they can work, and compensate the efficient one liberally, no man will spend his spare time trying to find out how to raise the wages of the other fellow. Workmen, as a rule, will do more work if their earnings are increased by so doing, and you will find great difficulty in getting the efficient ones into labor unions if they are not benefited by joining them.

"The second system of paying wages is called piecework. In the term 'piece-work' we include all the schemes for compensating men for what they do instead of for the amount of time they work. It may be divided into two classes, the first in which the price of a job is set from previous records or from the estimate of a foreman, who generally considers his work done when he has set the price. The second system of piece-work, when properly operated, provides a complete system of instruction for the workman, equitable compensation for his efforts, and opportunity for advancement on his own merits and not through pull or friendship. The essentials of this system, which have never failed to create a system of harmony and coöperation, are: —

"*a.* To have the very best expert available investigate in detail every piece of work, and find out the best method and the shortest time for doing it with the appliances to be had.

"*b.* To develop a standard method for doing the work and to set the maximum time which a good workman should need to accomplish it.

"*c.* To find capable workmen to do the work in the time and manner set, or to teach an ordinary workman to do it.

"*d.* When high efficiency has been attained, to compensate, not only the workman actually doing the work, but also those who supply him with materials and appliances to enable him to maintain the efficiency specified.

"*e.* To find among the workmen who have learned the best ways of doing the work some that can investigate and teach, and thus gradually get recruits for the corps of experts so that the system may be self-perpetuating.

"*f.* The ordinary foreman of the shop must not be called upon to do the work of the expert.

"It is a well-recognized fact that the efficient man at high wages is much more profitable to his employer than the inefficient man at lower wages.

"Inasmuch as the efficient workman often does two or three times as much as the poor workman, and does it better, and inasmuch as the workman who does twice as much work cuts the general expense per unit of output in half, there would seem to be no question that such a system of training would pay handsomely."

All this is sound practical philosophy, and its extensive application will do a great deal toward not only the reduction of capital and labor conflicts, and the limination of erroneous and unsound ideas as to necessary opposition of interests, but it will do far more — it will have a world-wide effect, for increase of efficiency of labor must necessarily have the same result as the use of labor-saving machinery has had, since it enables one man to do the work of two, three, or four. It is sometimes assumed that this sort of thing will mean the throwing out of employment of those no longer necessary, and it would if it all happened in a minute, but it will not if it happens in the naturally slow way. Early spinning and weaving machinery was smashed by the hand workmen, who thought there would be no more demand for them; yet the use of it so decreased the cost of cloth that the sales increased doubly fast, in a short time more weavers and spinners were at work than ever before, and, moreover, their labor was by no means so fatiguing or wearing as machine attendants as it was as hand workers. Precisely the same thing has happened in all lines; increased efficiency of workers, either by working faster or by machine assistance, however much it might seem to harm the class at first, has always benefited the class itself and the whole community by decreased prices, increased consumption, and all-round better living.

There is absolutely no doubt that the use of machinery and power is on the increase, that every old machine is constantly being studied to devise ways of improving it, and that equally deep study of the efficiency of labor, its proper compensation and welfare, will receive ever-increasing attention of the analytical sort, and that all the effects of this will be in the main beneficial and elevating to that nation that makes the greatest progress. What effect, then, will such an increase have on the conditions of living of the future? Will the flow to the cities continue, will more manufacturing cause more cities, and if so, how is this tremendous congestion of population to be housed and fed? While it is true that in the early days the factory created the city, to-day it is not; it is breaking up the city, and the reason is sound. Highest efficiency of processes and lowest cost of product demand saving in every way possible, so that the factory that can do its work in the country or small town simply cannot afford to stay in the city. It does not take a highly refined study to show how absurd it would be to build steel works at Broadway and Wall Street, when there are thousands of square miles of cheap land within reach of railroads. This fact alone will be sufficient to explain the tendency, now so common and ever on the increase, of relocating factories in small towns, or creating new towns in the open country as is being done at Gary, Indiana, by the United States Steel Co., and indicates that the city, if it is to increase at all, must find that increase based on other causes. Statistics show that while there is still a flow toward cities it has changed in character. Weber, in his "Growth of Cities," says: "The most rapid rate of increase of population is found in villages and small towns (2500 to 800) which are chiefly dependent for their prosperity upon manufacturing industries. The great cities, centers of trade and commerce, nearly rival the villages in rate of growth." Here, then, is the key, — the large cities are becoming, not the centers of manufacturing, but centers of trade and commerce, and their location and growth are now traceable to two causes, commercial and social. They will locate wherever there is a break in the transportation; railroad terminals, shipping ports, or points of transfer are to be city sites as they always have been. Their growth seems to be dependent just as strongly, however, on social conditions, described by Mr. E. S. Smith as follows: —

"Man naturally loves company and good fellowship. This seems to be the real basis of the drift from farms to the cities. All the attractions of city life are spread in the literature of the day. Men come to know more about the life outside of their own little horizon, and become restless to share other and more attractive callings. In the country it is quiet, with few pleasures, but in the city there is the hurry and excitement, stir and push of business, amusements of every sort, resorts of every grade where men may congregate and pass the time in congenial companionship. In the city also are the great educational institutions, museums, art collections, each making its appeal to the different types of man. There is a higher standard of living. Every man enjoys the comforts and luxuries of life."

While, therefore, as a result of good transportation and cheaper land in the small towns the manufactures will no longer be causal influences in city growth directly, they do, nevertheless, draw more and more on the farm or food-producing element of the population, which must be recruited, when the danger point is reached, not from the manufacturing and transportation working classes, but from the small trader class, with which the large cities swarm, and who seem to prefer an approach to starvation in the excitement of the city with but light labor to good, honest, hard work on farm or in factory. This danger point will not be reached, however, for some time to come, for although the farm population has been ever on the decrease in proportion to the city dweller, the output of the farm has been keeping pace fairly well by the application of the same principles of efficiency so highly developed in manufacture. In the United States, Weber says that the farm population was about 97 per cent of the whole, which had decreased in 1890 to about 70 per cent, and is probably less to-day. Yet increase of farming efficiency seemed to more than keep pace; for example, Powell shows that from 1896 to 1908 the whole population increased 24 per cent, whereas the agricultural exports increased in the same time 53 per cent, or more than twice as much. With regard to this same question of efficient farming, Davidson and Chase, in their book on "Farm Machinery," make the interesting comment that there were never over 400,000 Indians in North America, yet they were often in want of food.

Up to the year 1850 the old-fashioned hand methods of farming sufficed to maintain the balance fairly well, but at that time the steam-engine began to appear and stimulated the use of farming machinery. To-day practically everything can be done by machine when the farm is large enough to warrant its purchase. Plowing may be done by traction engines run by gasolene or kerosene; the seed planted by horse-drawn machines; grain cut and threshed, or corn picked and shelled ready for market; cream separated from milk, churned, and butter made; water pumped for stock and irrigation by power-driven machines; all of which remove the drudgery, and, taken together with the rotation of crops, cultivation, and the use of proper fertilizers and insect-destroying methods, enormously increase the productiveness of both the acre of ground and the man who tends it. In America, we have never had an abundance of farm labor, but the American inventor has surpassed the world in his ability to devise machines and methods, without which this country could never have been supplied with food; and this same ability, that has rendered efficient the manufacturing system, may be relied upon to continue to build up both, with continued and permanent prosperity for the nation that teaches its sons how to patiently study the little things which control the large ones, however remote the connection may seem to him who has not studied both profoundly and widely.

INDEX

C. A. N.