THE MOTOR CAR

A PRACTICAL MANUAL

R. W. A. Brewer

THE MOTOR CAR.

THE MOTOR CAR

A Practical Manual

FOR THE USE OF STUDENTS AND MOTOR CAR OWNERS

WITH

NOTES ON THE INTERNAL COMBUSTION ENGINE AND ITS FUEL

BY
ROBERT W. A. BREWER
Assoc.M.Inst.C.E.; M.I.Mech.E.; M.I.Automobile E.; M.S.E. (Gold Medallist, 1907)

With Numerous Illustrations

NEW YORK
D. VAN NOSTRAND COMPANY
23 MURRAY AND 27 WARREN STREETS
LONDON
CROSBY LOCKWOOD AND SON
1909

TO

A VALUED FRIEND

WHO HAS ENCOURAGED ME IN MY EXPERIMENTAL
WORK AND ASSISTED ME IN THE REALISATION
OF MY AMBITIONS.

PREFACE.

THE information given in this book was originally delivered by the Author in the form of lectures at the Crystal Palace School of Practical Engineering, the Royal United Service Institution, and the Royal Automobile Club. There appeared to be some demand for a practical work on these lines, so his notes have been enlarged for publication.

The Author decided to commence at the beginning of the subject, and to explain the evolution which had to take place in internal combustion work before the modern motor car could become a commercial possibility. The fundamental principles governing the action of the engine are discussed under the heading of Gas Engines; the action of these larger and somewhat cruder machines is more easy to grasp.

Some of the theories advanced by the Author are founded upon his experience in internal combustion and motor car work, his investigations dating from the year 1892. A certain amount of space is devoted to the discussion of liquid fuel and its utilisation, a subject to which the Author has given particular attention for some years. The final chapters are of a practical nature, dealing with the management and maintenance of a motor car.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

THE MOTOR CAR.

CHAPTER I.

HISTORY OF THE INTERNAL COMBUSTION ENGINE.

It is impossible to say exactly when the first internal combustion engine was made.

The first record we have is of Denis Papin's engine in 1690. Papin exploded gunpowder in a cylinder, the pressure of the expanded gases thus obtained being used to move a piston in another cylinder.

Robert Street patented an engine in this country in 1794. It consisted of a cylinder containing a piston, which was connected to a pump by means of a lever. The bottom of the cylinder was heated, and a little spirits of turpentine introduced and evaporated by the heat. The piston was drawn up, and air allowed to enter and mix with the vapour. The inflammable mixture was ignited through a hole in the cylinder. Street's method was crude, but the idea was right, and has only been improved on recently.

In 1826 Samuel Brown patented an engine. In this engine the air was driven out by a flame in the cylinder. A jet of water was then made to play on and cool the cylinder, which created a partial vacuum, allowing the atmospheric pressure to do work in moving the piston.

W. L. Wright was an important patentee in 1833. He produced the first two-cycle engine. His engine was supplied with gas and air, from two separate pumps, and

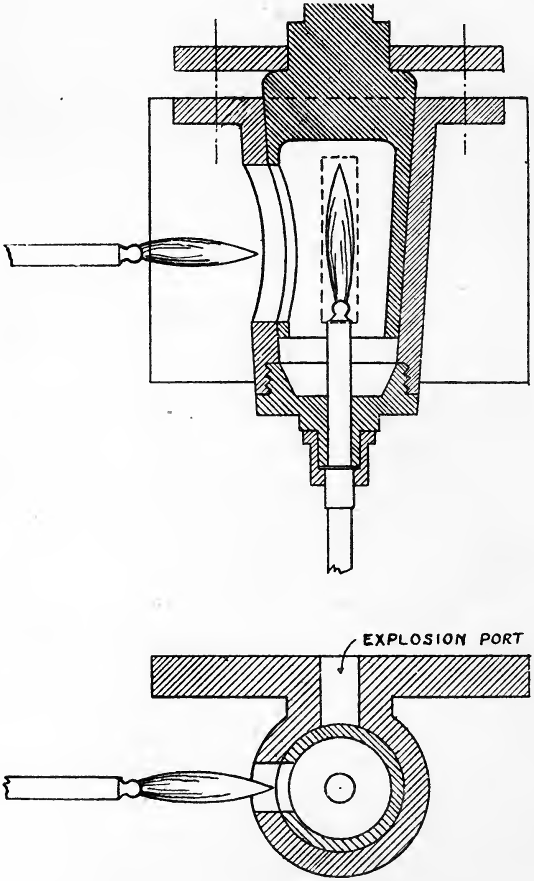


Fig. 1.—Barnett's Igniting Cock.

the cylinder and piston were water-cooled. It seems doubtful whether this engine was ever actually made, but it was carefully designed in all its details.

Barnett's patents, dated 1838, are worthy of special attention. To him are due three engines, one single acting and two double acting, also a very ingenious igniting device.

Barnett's igniting cock consists of a hollow plug, fitted accurately into a container. The container has two slots, one communicating with the combustion chamber, the other with the atmosphere. The plug has one slot so arranged that when opposite the slot in the container, which is in communication with the atmosphere, the slot in the container leading to the combustion chamber is closed, and *vice versa.* A gas jet is brought into the centre of the plug, and another pilot jet is placed outside the plug, as in the sketch.

Consider both gas jets to be alight. Just before the time of ignition occurs, the plug is turned so that it is closed to the atmosphere; on turning a little further, the slot in the plug comes opposite the slot in the container which is in communication with the combustion chamber and the gas flame ignites the mixture in the engine cylinder. The explosion extinguishes the gas jet, but on turning the plug, the pilot jet ignites the other jet through the slot in the plug.

This igniting device was a great improvement on the earlier methods, and has been used on many engines since, and it is to be found on some old engines at the present time.

Barnett's third engine is the most interesting, in that it is double acting. Two pumps, for air and gas respectively, are connected through a two to one gear to the crankshaft, so that the pumps make two strokes for one of the motor piston. The engine being double acting, explosion takes place at both ends of the cylinder, and an exhaust port in the middle allows the burnt gases to escape. The gas and air are forced into the cylinder by the pumps, and the piston, coming up or down as the case may be, completes the compression.

It will thus be seen that Barnett was the first to compress the mixture in the actual working cylinder.

In 1855 Newton patented a double acting gas engine, the chief feature of which was a new form of igniter. It consisted of a hollow piece of metal placed in a recess in the cylinder, and kept red hot. When the piston uncovered the recess, the explosive mixture was ignited. Modified forms of this type of igniter are still in use.

A free piston engine was invented in 1857 by Barsanti and Matteuci.

The free piston engine is from a theoretical point of view, the most economical known. The reason for this will be touched upon later on.

The principle of the engine is as follows:—

The piston which is contained in a long cylinder is free to move at the time of explosion. Expansion takes place rapidly, and the piston rises. When the piston has reached the top of its stroke, a partial vacuum has been formed in the cylinder. The atmospheric pressure acting on the piston, together with its own weight, cause it to descend. During the down stroke, a rack attached to the piston engages with a pinion on the engine shaft by means of a clutch, and the shaft is rotated.

Up to this point, gas engines were in a merely experimental state.

The last engine described was theoretically good, but the inventors seem to have failed in overcoming the mechanical difficulties involved in making their engine a commercial success.

To Lenoir is due the credit of introducing an engine which was, comparatively speaking, of commercial utility. His engines were made and used for a variety of purposes in France.

In 1860 the Lenoir patents were taken over in this country by J. Johnson, and a number of engines made and sold. The engine was like an ordinary steam engine, gas and air being admitted at atmospheric pressure, and ignited. Exhaust was carried out as in a steam engine. Careful mechanical design, and attention to details, seems to have contributed largely to the success of Lenoir's engine.

At this point it will, perhaps, be advantageous to discuss briefly the necessary mechanical requirements, and the difficulties which had to be overcome, in order to obtain an efficient engine. These may be summarised as follows:—

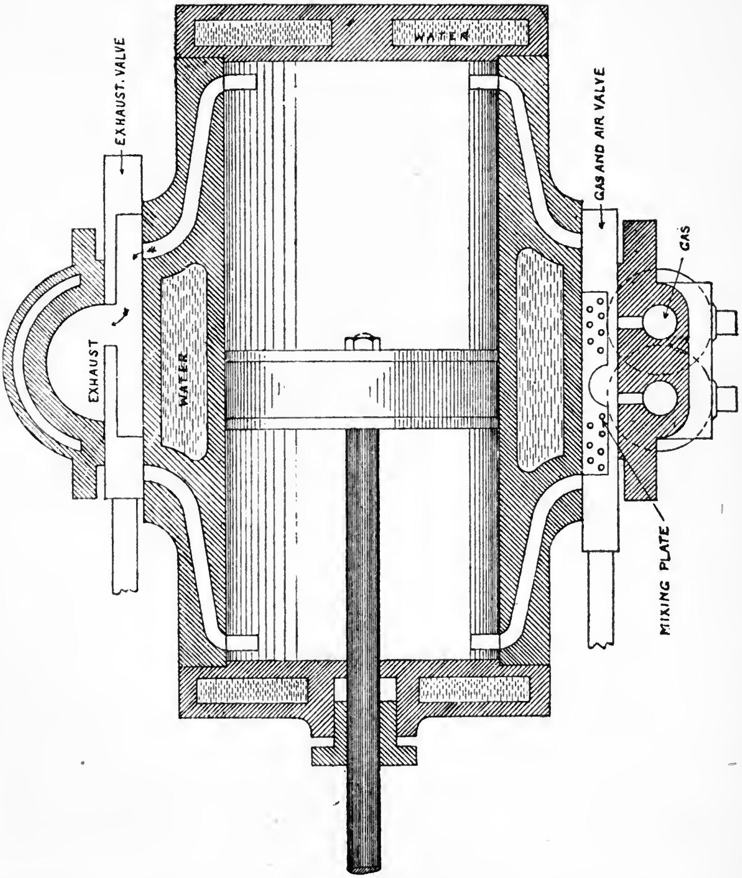


Fig. 2.—Lenoir's Engine.

1. A cylinder in which a piston can work freely, and be effectively lubricated.

2. A combustion chamber, containing valves and valve seats, which can be so connected to the working cylinder that the joints will remain tight under large variations of temperature and pressure.

3. A reliable system of firing the explosive charge within this chamber.

It will be seen, on consideration, that the above axioms embody all the points in successful design and working of the gas engine.

Million in 1861 and Beau de Rochas in 1862 investigated the effect of compression in gas engines. The latter gave the following conditions as essential, in order to obtain economy :—

1. Maximum cylinder volume with least possible radiating surface.

2. Greatest possible rapidity of expansion.

3. Greatest possible volume of expansion.

4. Greatest possible pressure before ignition.

The consideration of 2 and 3 will explain the great advantages of the free piston engine referred to above.

Beau de Rochas came to the conclusion that, in order to comply with his deductions, large cylinders would have to be used, and the resistance of the gases reduced to a minimum. This led him to suggest the following cycle of operations :—

1. A suction stroke, drawing air and gas into the cylinder.

2. A compression stroke compressing the mixture.

3. Ignition at the end of the compression stroke, and expansion during the third stroke.

4. Exhaust stroke, expelling the burnt gases from the cylinder.

Otto employed this cycle in his second engine with great success. He first, however, in conjunction with Langen, introduced a free piston engine, which was a long way in advance of anything which had been done up to that time. It differed from the Barsanti engine only in the perfection of its mechanical construction and in an improved firing device of the flame type, known as the Otto & Langen slide.

The Otto & Langen free piston engine was exhibited at the Paris Exhibition in 1867. The gas consumption was 44 cub. ft. per B.H.P. hour, about half the consumption of the Lenoir engine. In spite of its noisy operation, its increased economy in working caused it to leap into popularity.

These early Otto engines were manufactured and sold in large quantities until 1876, when Dr Otto introduced his famous "Otto silent engine," using the cycle suggested by Beau de Rochas. The gas consumption of the Otto silent engine is from 17 to 22 cub. ft. per B.H.P. hour.

Messrs Crossley Bros. manufactured engines under the Otto patents for twenty-one years, during which time, until the patents expired, no great improvements were made in the design, excepting the introduction of an improved "hot tube ignition."

The most reliable form of hot tube igniter consists of a metal tube closed at one end, and connected to the combustion chamber at the other end by means of a valve. The tube is kept hot by an external flame, the valve being operated from the engine shaft by a suitable arrangement, so that ignition takes place at the proper time.

Care has to be taken to prevent the tubes becoming too hot, and they have to be renewed frequently on account of the increased oxidisation at the high temperature at which they work. The metal tube was later given up in favour of porcelain.

Electric ignition was first applied successfully by Lenoir. He used a battery, induction coil, distributor, and sparking plug. Troubles due to insulation difficulties, and failure of spark due to moisture on the sparking points, caused this method to be given up in favour of flame, or hot tube ignition.

Until quite recently the hot tube igniter was universally used, and is indeed still preferred in some cases for small gas engines.

Within the last three or four years, however, electric ignition has again come into favour on account of the ease with which the firing point can be governed, and also because of the danger of using a naked flame in the vicinity of petrol or other inflammable vapours.

Electric ignition methods may be divided broadly into two classes, the primary and secondary, or high and low tension.

The best form of primary ignition is, perhaps, that in which a movable striker makes and breaks contact inside the cylinder. This method gives a good spark and seldom misses fire, but as it involves a gland in the cylinder head, which increases the chance of leakage of the gases under compression, it is now being superseded by the high tension or secondary system.

Secondary or jump spark ignition is now almost universally used, and is met in many forms. These may be divided into two classes :—

1. High tension ignition, by means of accumulators or batteries supplying a low tension current to the primary winding of an induction coil, which the secondary winding transforms into a high tension current. This is led to the terminal of a sparking plug, screwed into the combustion chamber of the cylinder, by one wire, the other end of the circuit being earthed to the engine casting.

2. Magneto ignition of the high tension type, for which the current is mechanically generated by means of a magneto—or small dynamo having a field consisting of permanent magnets—and an armature of the shuttle wound type. The current in the armature is generated

by means of either partial or total rotation of the armature itself in the magnetic field, or by the movement of an inductive sleeve between the armature winding and the pole pieces of the magnets. The action of the ignition systems will be fully explained in a later chapter.

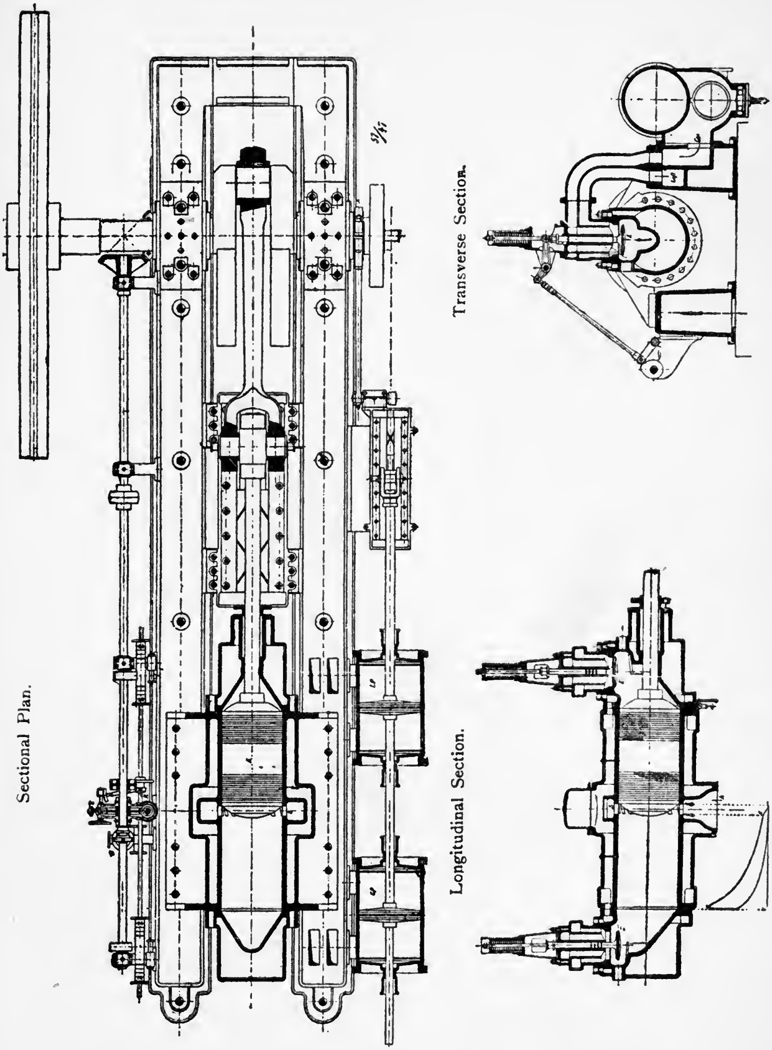
CHAPTER II.

TWO-CYCLE ENGINES—LARGE ENGINES—SCAVENGING.

THE want of frequency of impulse in the Otto cycle causes large engines working on this cycle to become heavy and cumbersome. In order to increase the frequency of impulse, and thus get more power for a given weight of engine, Mr D. Clerk, about twenty-five years ago, introduced a two-cycle engine, working on what is known as the Clerk cycle.

In this engine the charge is introduced by means of a pump, and exhaust takes place through a number of ports, uncovered by the piston at the end of its out-stroke. When the piston has almost completed its working stroke, the exhaust ports being uncovered, the mixture of gas and air from the pump sweeps out the burnt gases and fills the cylinder. The piston then returns and compression takes place. The cylinder head is made conical to prevent the incoming charge from passing through the burnt gases, and escaping through the exhaust ports.

In comparing the Otto and Clerk cycles, Mr Clerk draws attention to the fact that, for a given rate of revolution, the Otto type of engine allows three times the time interval to charge the cylinder that it is possible to allow in the Clerk cycle. This means that for a given valve area the Clerk cycle engine requires a greater expenditure of power to charge than the Otto cycle engine. He also points out the difficulties of fully charging the cylinder of a Clerk cycle engine without loosing a certain amount of the



Sectional Plan.

Longitudinal Section.

Transverse Section.

FIG. 3.—The Körting Engine.

charge. On account of these difficulties, although in a small engine with a comparatively light load the economy very closely approaches the best Otto economy, yet the maximum efficiencies possible with the Otto cycle have not been attained with any two-cycle engine.

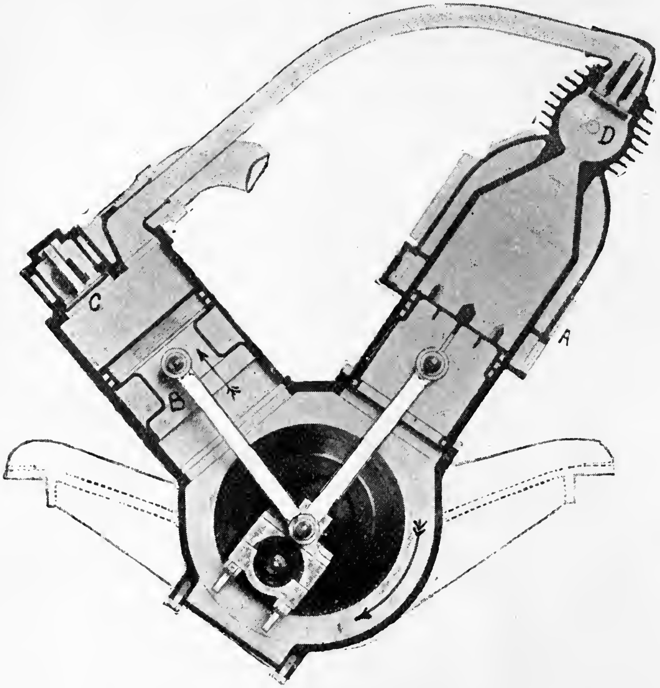


FIG. 4.—The Dolphin Petrol Engine.
(Working on the Clerk Cycle.)

The Körting engine is a modern application of the Clerk cycle. It is double acting, combustion taking place on both sides of the piston. A charge of air is first introduced to drive the burnt gases forward, then gas is admitted through the same valve. The object of mixing the air and gas in the cylinder is to prevent an explosion in the pump, which, although of little importance in small engines, becomes serious in large sizes.

In engines working on the Clerk cycle, it will be noted that, on account of the increased number of explosions per revolution, there is more heat to be dissipated in order to safeguard the cylinder and other working parts.

Great difficulties are met with in the working of large gas engines. In spite of improvements, such as water-cooled pistons and improved balanced and water-cooled valves, and many other details, there is still a great field for improvement, quite apart from the question of improved economy.

The extraction of some of the heat from blast furnace gas has engaged the attention of engineers for many years. Blast furnace gas has been and is used for steam raising purposes, but it is found that the heat energy can be more efficiently used in gas engines specially designed for the purpose.

The chief difficulty in the use of blast furnace gas is the presence of particles of incandescent dust; these, besides the danger of pre-ignition which they introduce, are apt to cut the cylinder and valves. The gas has also a relatively low calorific value.

In order to keep the cylinder as clear from dust as possible, engines using blast furnace gas are of necessity fitted with some form of scavenging device.

The Oechelhauser engine is largely used with blast furnace gas, usually to provide power for blowing. This engine has two opposing pistons working in the same cylinder. There are three crankpins on one crank. The main crankpin is driven by the nearer piston, the other two pins, placed at 180 deg. to the main pin, are connected by means of side rods and crossheads to the other piston. The pistons thus move apart with equal velocities, giving a very smooth and well-balanced engine.

The admission of gas and air, and exhausting, is effected through ports in the cylinder, no valves whatever being employed. One piston uncovers the exhaust ports, whilst the other uncovers the air inlet ports, admitting a scavenging charge of air from a pump; then, when the piston moves a little further outwards, another set of ports is uncovered, admitting gas and air. The gas and air act as a scavenging charge, and expel the remains of the burnt gases, and compression then takes place. The fact that the engine has no valves, and can have large exhaust and inlet areas, makes it specially suitable for use with blast furnace gas. It is, however, rather an expensive engine to manufacture.

The Premier is another engine which works successfully on blast furnace gas. The designers of the Premier engine have paid special attention to scavenging. Compressed air at a pressure of about 3 lbs. per square inch enters the cylinder through a valve, before the exhaust stroke is completed, sweeping the exhaust gases out. When the piston has passed the dead centre, a charge of air and gas is admitted. The compressed air is obtained by a separate pump.

Crossley Bros. Ltd. introduced the inertia scavenger, which depended for its action on the inertia of the exhaust gases passing through a long pipe. The inertia was used to draw a charge of air through the inlet valve into the cylinder and so cleanse it. Positive scavenging, as carried out in the Premier and Oechelhauser engines, gives the greatest satisfaction.

The gas engine at its present stage of development is one of the most perfect, if not the most perfect, prime mover, even rivalling the steam turbine in many cases, and particularly so in the smaller sizes. For any given weight of machinery, too, it is possible to construct an internal combustion engine of far greater horse-power than in any other type of reciprocating engine with its attendant boiler and other necessary gear. The Tourist Trophy race in the

Isle of Man in 1908 shows that with four 4-in. diameter cylinders it is possible to generate more than 100 H.P. on test. The limit of weight cutting is reached in the small high speed engines which are employed for aeroplane work, and these have proved to be quite reliable as well as easy of manipulation. It cannot, however, be said that the internal combustion engine has, even in its present high state of development, reached finality, as from time to time drastic departures are made from what has been recognised as a standard type. The Knight engine, for instance, is a complete departure from the ordinary engine fitted with valves, and it may be that a perfect rotary engine will be evolved in the near future. But whatever the mechanical application is, the underlying principle of the combustion of a gaseous mixture within the working chamber will remain, and the thermo-dynamic theories will equally well apply.

CHAPTER III.

MECHANICAL DETAILS OF CONSTRUCTION.

PISTONS, BED-PLATES, AND STRESSES IN THE SAME—THE SHAPE OF MAIN BEARINGS—LINERS.

IN the two previous chapters a sketch of the development of the gas engine from the earliest times up to the present day is given, and it is now necessary to consider certain mechanical details of gas engines of various sizes, in order to understand the difficulties which have to a great extent been overcome, and have made this type of prime mover a practical success.

Pistons.—The majority of engines manufactured in this country are working on the Otto cycle. The diagram of the National engine gives a general idea of the arrangement of the engine. A trunk piston is almost universally employed, as it is easy to examine and remove for cleaning, and its adoption enables a shorter engine to be constructed and makes it possible to dispense with a piston rod and crosshead—the piston itself taking the thrust due to the angularity of the connecting rod. The trunk piston has another important advantage in radiating the surplus heat generated in the combustion chamber.

A trunk piston has a large amount of radiating surface equal in area to the circumference of the inside of the piston multiplied by its length, plus the area of the exposed piston head. In the case of an enclosed piston, however, there is no external radiating surface.

The radiation from an open type of piston is assisted by the pulsation which is naturally set up when the piston moves forward and backward into the cylinder, and this pulsation is always set up. In addition to the cooling of the piston there is undoubtedly a certain amount of cooling of the cylinder walls with an open ended cylinder. These pistons are always made in small engines in a single casting which has grooves turned in it in the same way as a locomotive piston, or any piston which is fitted with Ramsbottom rings. That is the simplest packing ring for the purpose of keeping the joint tight, and it is made by taking a cylindrical piece of cast iron, fixing it in the lathe, turning and boring it and slicing off rings to the size required. The ring is turned slightly larger than the bore of the cylinder, and is then cut diagonally or tongued and grooved. This slightly reduces the size of the ring, which is then, in the best practice, clamped together and ground a true fit. In the horizontal gas engine the type of joint does not materially matter, but in the high speed vertical engine, as in the steam engine, the joint must be perfectly tight. The reason is as follows:—There is a long piston of considerable weight, and this piston also does duty as a crosshead. In the ordinary steam engine with an enclosed piston, the crosshead and its two slippers take the thrust due to the angularity of the connecting rod.

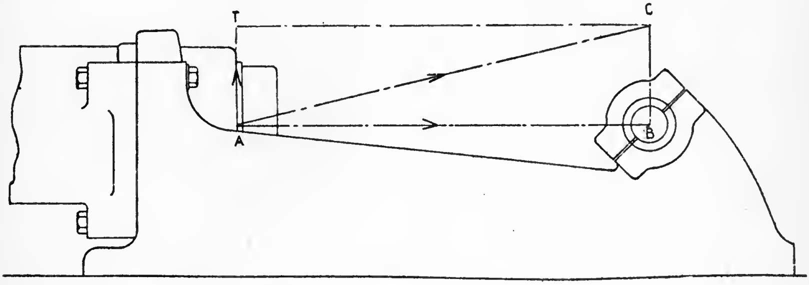


FIG. 5.—Stresses in a Bed-plate.

Referring to the triangle of forces in the diagram, the magnitude and direction of the thrust along the connecting rod is represented by AB. This force can be resolved into two forces whose magnitude and direction are represented by AC and BC, the force acting along AC tending to rupture the bed. The force BC is resisted by an equal and opposite force which is acting upwards through the point A, its magnitude representing the pressure on the guide. In the gas engine there is no crosshead, the trunk piston acting both as a piston and as a crosshead. Following upon the argument there is a good deal of pressure upon the bottom edge of the piston, and advantage is taken of it to keep the piston joint tight along the bottom edge in the following manner.

When the rings have been assembled in their proper grooves they are turned so that all the joints lie along the bottom edge. The weight of the piston added to the thrust upon it, keeps a tight joint along this portion of its circumference, but owing to the diameter of the piston itself being slightly less than the diameter of the cylinder, to allow for expansion of the heated piston in working, the rings are relied upon to spring out and complete the joint around the top and sides of the piston. This arrangement keeps perfectly tight when the engine runs in a right-handed direction, looking at its side elevation, the cylinder being to the left hand of the observer. However, in engines with opposed cylinders, one engine is of necessity left handed, which means that the thrust is taken on the top of the piston instead of at the bottom. It is therefore necessary with large engines to fit a slipper piston, that is a piston with a loose slipper on the top which can be packed out to fit the cylinder and thus prevent the piston from lifting unduly in working.

Bed-plates.—The usual form of the bed-plate of the gas engine is shown in Fig. 5. This has for many years been found a convenient type for small and medium sized engines. Theoretically speaking, however, this type of bed is not one which is loaded in a favourable manner when subjected to the shocks of the explosion. It will be noticed that at the time of maximum loading, *i.e.*, when the charge is fired and the piston is at its inner dead centre, the stress is along the connecting rod which is at the moment situated on the centre line of the cylinder and the main bearings. Now, considering the bed as offering an equal and opposite resistance, in order to have equilibrium in the system, we have the following stresses :—

There is a compression on the connecting rod, the magnitude of which is the firing pressure in the cylinder, some 350 or 400 lbs. per square inch, multiplied by the area of the piston. This stress must be resisted by the metal of the bed-plate, so that the net load upon the bed-plate is a tension upon its cross sectional area. We may take it that the neutral axis of this area passes through its centre of gravity, and it will be obvious from the figure that a line passing through the centre of gravity, and parallel to the centre line of the cylinder and main bearings, falls some distance away from this centre line, and the loading along the connecting rod passes outside the section of the bed-plate altogether. Had this line of loading passed within the middle third of the area, there would have been no reversal of stress, but under the prevailing conditions there is a bending action at the centre of the bed in addition to the tension. The bending moment is the total pressure along the connecting rod multiplied by the distance apart of the centre line of the engine, and that of the centre of gravity of the section of the bed. This bending action increases the tension along the upper side of the arms of the bed very considerably, and also sets up severe stresses in the outer horns of the main bearing pedestals.

These stresses should be carefully borne in mind in designing a bed of this type, which is also subjected to initial stresses in cooling, owing to the unequal displacement of metal.

The suspension of the cylinder from the bed is carried out in several ways, the usual Crossley practice being to form the cylinder end of the bed as a stiff ring, and to bolt the lugs of the cylinder, some three in number, to this ring.

Another practice is to form a complete flange on the cylinder casting, which is then bolted to the ring. The object of this construction is true machining in the first instance, as the flange on the bed is bored and turned at the same time as the main bearing pedestals are bored, and on the same machine, thus ensuring perfect alignment.

Another method is to plane two horizontal bearers somewhat below the centre line of the cylinder, to which horizontal flanges on the cylinders are bolted. This makes a much stiffer job, but is perhaps more difficult to line up. For large cylinders this latter method is to be preferred as there is no overhung cylinder weight upon the bolts.

In large engine practice, the strength and stiffness of the bed-plate becomes an important factor, and it is therefore usual to build girder frames in place of the type previously discussed. The object of this type of frame is to bring the tensile stresses within the middle third of the sectional area. These frames usually consist of a pair of arms supported on a pedestal with a large footstep under the main bearings. These arms are separate from the cylinder and bolted to it, the cylinder itself resting upon a footstep of ample dimensions.

When two cylinders are in tandem at one end of a girder frame, allowance must be made for the expansion of the front cylinder, which is considerable, and would cause too much compression of the explosive mixture in one cylinder, and too little in the other. It is therefore necessary to so design the frame and its attachment to the cylinders that expansion of the cylinders and the connecting rod between the two pistons will not affect the compressions of the gases in the two cylinders. Single-ended girder type engines should preferably have the main bearing cap designed with a lip on either side so as to bind the two horns together. This cap when well fitted will relieve the stress on the outward horn, transmitting a portion of it to the inward horn. Caps should never be made facing away from the cylinder, as that entails stresses being borne by the cap bolts, the cap tending to lift off at the moment of firing.

Bolts in tension behave similarly to a notched specimen in a testing machine, and the breaking stress upon the notched or reduced area is not proportional to that which would be carried by a parallel specimen. This is accounted for by the fact that a notched specimen does not permit the final contraction of area before fracture which it would do if it were parallel.

Bearings.—An important point in the design of main bearing brasses for large gas engines is the position of the division. Diagonally divided brasses are a mistake, as the wear invariably takes place vertically downwards, and it is impossible to line up a diagonal brass correctly to allow for this. This vertical wear is due to the weight of the flywheel, and the brasses should therefore be horizontally divided. A large brass becomes rather an unwieldy piece of material, particularly when adjacent to a flywheel weighing, say, twenty tons, so that large brasses are generally made in four pieces. There is a small brass at the bottom of the shaft, a small brass at the top, and two side brasses. Packing or wedge pieces are necessary for adjustment at the sides which fit in quite simply, and a cap is bolted on the top. It is very clear with a brass of that nature that by moving the two wedge pieces, and taking the weight from the shaft, the bottom brass can be slipped in from the side. Sometimes the side shaft may come past the end of the brass, so that when this four section type of brass is used, care must be taken to allow the necessary clearance for drawing the brass.

Liners.—In gas engine practice, the main cylinder casting is fitted with a separate liner, in which the piston works, and an annular space is arranged between the two, forming a water jacket.

These liners are always made of a special close-grained cast iron, and as they are water jacketed, they have to be provided with a watertight joint at each end and provision should be made for expansion.

Different makers have adopted different methods of fixing the liner to the cylinder head. Some makers have four or more lugs cast on to the liner at the back end; then sufficient space has to be allowed to get the lugs in. In another case the liner is made parallel. In the Crossley engine the liner is held by six bolts which are attached to the liner from the back of the cylinder, pass right through the water jacket, and are tightened up outside the cylinder at the back. In order to fit the liner into the cylinder, a joint of correct size must be cut and applied to the end of the liner to be fixed to the face turned on the cylinder head for the purpose. The bolts are then placed through the holes and draw the whole liner up tight into place. In an arrangement of this kind, it is impossible to see whether the joint is being made correctly, therefore, with a large engine, such an arrangement is practically impossible. For this reason, large cylinders are made with a loose breech end which allows the liner to be fitted in from the back. When it is screwed home, the breech end is then bolted up into place.

Considering now the outer skin of the liner which is in contact with the water. In addition to the smooth surface of radiation which is provided in the small engine, it becomes necessary in the large engine to make additional provision for radiation, as well as additional strength to the explosive chamber. In this respect the liner is comparable to a large gun. The breech end of the gun where the explosion takes place is wound round its circumference with steel strip. In the case of a cast-iron liner, however, it is inadvisable to wind strip upon it. A fairly cheap casting is made with stiffening rings and increased radiating surface, for it becomes absolutely necessary in large engines to cast these rings upon it for the foregoing purpose.

A hand hole, with removable cover, is a great convenience for washing out the water jacket of a breech end, as this casting contains many pockets between the ribs where lime and dirt can accumulate. It is most important that gas engine cylinders be well designed and proportioned in order to avoid undue internal stresses being set up in the castings when cooling.

CHAPTER IV.

DETAILS OF THE MOVING PARTS.

Water Cooling.—The enormous temperature which is reached when an explosion takes place in the combustion chamber of large engines tends to heat the piston unduly unless proper precautions are taken to dissipate this radiated heat. It is absolutely essential, therefore, to employ water cooling for large pistons, when they are anything like the diameter of 30 in. A large number of methods have been adopted by different firms for watering these large pistons. Crossleys fit an arrangement which the firm has been using for a number of years. There are about four moving pipes, two to each side of the piston. These are made of brass with universal joints, through which water passes to the piston head, one side an inlet and the other side an outlet. This arrangement answers its purpose as long as it keeps tight. There are several other methods of watering a piston. Supposing, for instance, a plunger is fitted at each side of the bed-plate working into sleeves or tubes fitted to the piston. These two plungers, working in their sleeves, allow water to pass to the pistons every time the piston comes out or returns; these plungers act as pumps and can pump water from any convenient place and allow it to pass through a hole up the centre of the plungers, and through the pumps into the piston from whence it may return by gravity through a hole at the bottom. This is more

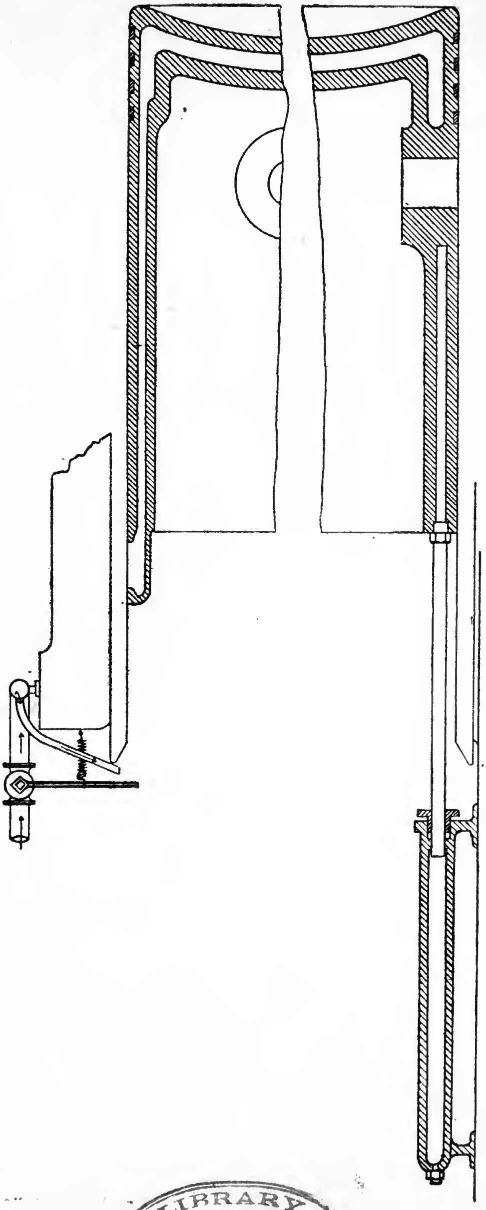


Fig. 6.—Two Methods of Water-cooling Pistons.

mechanical than the swinging arm arrangement, and has been adopted by certain firms. Another method of watering a piston could be adopted; this consists of fitting a small cup to the top of the piston at the front end. Every time the cup comes forward, it taps a small cock and opens a water supply. This would answer perfectly well, and the water could run away by gravity from the bottom of the piston.

Connecting Rods.—The arrangements made on small ends of connecting rods are different in gas engines from steam engines. A gas engine only has an impulse at one end of the piston, and so all the load comes on the front end of the brass. There is one point in the cycle of operations when the load is reversed to a certain extent, and the amount of load reversed is the amount required to retard the piston when it is coming to rest at the end of the exhaust stroke.

The small end of the connecting rod should be easy of access, and have means of making a fine adjustment in a short time. This can best be done by the use of wedge gear, a hole being drilled in the piston to enable a box spanner to screw up the wedge without drawing the piston. This fine adjustment will be appreciated by any one who has had charge of gas engines. An objectionable knock is most tiresome to remedy unless suitable means are provided. A mean bearing pressure of 600 lbs. per square inch is allowed on the gudgeon pin, the effective length being about 1.5 times the diameter. The large end of the connecting rod is undoubtedly best made on the marine pattern. The brasses should be stiff enough and thick enough at the crown to prevent opening out. Some large ends are made forked, with a back half-moon brass to take the load. The objection of heavily loading a half-moon brass is well known to those who have had experience in this direction. It is not an uncommon thing for half-moon brasses to crack right along the crown. It is much easier to fit a marine brass on a flat tee-ended rod, and there is little likelihood of the brass cracking. The bolts for these brasses should be of sufficient diameter to take any undue load or shock which may come upon them, as, for instance, would be produced if the nuts become eased, or the brasses slack. Connecting rod bolts of insufficient strength have caused many serious accidents. As an instance of what occurred in one engine, a knock developed in the large end of the connecting rod, but was allowed to go on, and increased to such an extent that eventually the cap bolts broke. It is perfectly obvious that when the bolts break the whole engine is likely to be wrecked. In this case the piston flew out, the crank came over, and the connecting rod was knocked through the bed-plate.

Connecting rods in gas engines are submitted to sudden heavy loads in compression, of a magnitude often not fully recognised. Suppose, for example, the compression amounts to 100 lbs. per square inch, and at the moment of firing the pressure rises to 350 lbs. per square inch, there is a sudden load of 250 lbs. per square inch, which, in the usual way, we equate to a dead load of 500 lbs. per square inch. The load in compression is then 600 lbs. per square inch of piston area, and the rod is practically a free-ended strut. Assume a piston diameter of 10 in., and a connecting rod 48 in. long.

By Unwin's formula the diameter of this rod $= d$.

$$d = 0.038 \sqrt{\{Dl\sqrt{p}\}}$$

$$= 0.038 \sqrt{10 \times 48 \times 18.75} = 3.6 \text{ in.}$$

$p =$ initial pressure $= 350$ lbs. per square inch.

$l =$ length of rod in inches.

$D =$ diameter of cylinder in inches.

The buckling load of this rod $= C$.

$$C = \frac{S}{1 + ar^2} = \frac{67000}{+\frac{710}{370}} = $$ 23,000 lbs. per square inch buckling load, when considered as free ended,

$$r = \frac{l}{d} \text{ and } l = 2 \times 48,$$

$$a = \text{for mild steel } \frac{1}{370},$$

s = for mild steel 67,000 lbs. per square inch.

The total load on the piston $= 78.5 \times 600 = 47,100$ lbs. —a factor of safety of 4.9. But where do we find a connecting rod $3\frac{1}{2}$ in. diameter on this size of engine?

Perhaps the rod could be considered as steadied by the piston to a certain extent, so that the value of l might be modified. This calculation takes no account of the centrifugal force, which increases the bending action. Flat connecting rods are used in the Westinghouse engine, as is the custom with some American steam engines.

Cranks.—Bent cranks have almost been discarded. Nearly all the better class of engines are now made with cut or slotted cranks. One of the chief reasons is that the outside bearings can be brought closer together, thus reducing the bending moment at the crankpin and webs. The nearer the brasses are to the webs of the crank so much is the crank as a whole stiffened.

Flywheels.—The gas engine flywheel has to be made very large in comparison with the size of the engine because there is only one working stroke in four. During that working stroke enough energy must be stored to maintain the other three strokes, and at the same time continue the work of the engine throughout these other three strokes. All the resistances must be overcome, and all the work has to be done by the flywheel during the three idle strokes. It becomes a difficult matter to obtain regularity of running within the limits of good gas engine practice, namely, not more than 2 per cent. variation of speed in any part of the cycle of operations. The formula for the storage of energy in a flywheel is obtained as follows:—

(1) $$\frac{wv^2}{2g},$$

where v = velocity at mean radius in feet per second,
g = acceleration of gravity = 32.2 ft. per second per second,
w = weight of moving mass in pounds.

Now the limit of velocity depends on the centrifugal force, and f being this force—

(2) $$f = \frac{wv^2}{gr},$$

where r is the radius of gyration of the revolving mass in feet.

For ordinary work this radius of gyration may be taken as the radius of the centre of gravity of the section.

Now the forces tending to cause rupture must be resisted by the material forming the rim of the wheel. Considering a unit section of rim width say 1 in., we have—

(3) $$PD = 2St,$$

where P = the pressure in pounds per square inch = f in formula for centrifugal force (2),
D = diameter of wheel in the same units as r in (2), say feet, and taking t as 1 in.

$$PD = 2St,$$

$$P = \frac{wv^2}{gr} \text{ (from 2), and}$$

$$W = 3.1 \text{ lbs. per foot length for 1 sq. in. section;}$$

then S (the stress in the material) $= \frac{PD}{2} = \frac{wv^2 \times r}{gr}$, as $\frac{D}{2} = r$.

$$\therefore S = \frac{3.1 \times v^2}{32} = \text{approximately } \frac{v^2}{10}.$$

This gives the stress in the material as one-tenth of the square of the linear velocity approximately, for a cast-iron rim.

The exact mass of the rim to satisfy any particular set of conditions or limit of variation depends on many other considerations, such as the intensity of pressure at the firing point and the limit of time between the impulses, and is too complicated to be discussed fully here. At the present time, authorities still disagree as to what should be the correct weight of wheel in certain cases, and in calculating by three or four different methods the results vary as much as 100 per cent.

However, from the previous formula (3), it will be seen that the most economical method is to keep the velocity as high as possible within practical limits, and taking 10,000 lbs. per square inch as the ultimate breaking load of cast iron such as is used in flywheel castings, the safe load would not much exceed 1,000 lbs. per square inch in actual practice.

It is usual to allow a maximum velocity of a mile a minute for the flywheel rim, and it is assumed that the whole of the load is taken by the mass of the rim, and that the centre of gravity is the centre of the rectangular section of the rim. When a large amount of energy has to be stored in a flywheel, the resulting design makes the casting of rather irregular and abnormal dimensions. The size of the arms of the flywheel should allow sufficient strength to bring the wheel to rest in one revolution.

Owing to the fact that the flywheel receives energy during only one stroke in two revolutions at the most, a heavy duty comes upon the keys. Not only has shearing to be considered, but the main tendency is for key-ways to nibble the edges of the keys. Large bearing area must be provided to meet this, and it is usual to fit two keys, a quadrant apart, to all large flywheels for gas engines.

Valves.—Valves are about the most important detail in the modern large gas engine. Mushroom valves are adopted in gas engine practice because this type of valve opens very readily to its full area and shuts just as readily, and the area is either fully opened or it is fully closed. But with large sizes of mushroom valves the whole pressure on the head of the valve becomes very considerable, and increases naturally with the size of the valve. In order to open a valve of considerable dimensions with about 50 lbs. per square inch pressure on the back of it, very considerable effort is required to overcome the resistance, which is equal to the pressure in the cylinder multiplied by the area of the valve. There are two or three methods of actuating mushroom valves. One method acting through a rocking lever is shown in Fig. 7. A cam on the half-time shaft

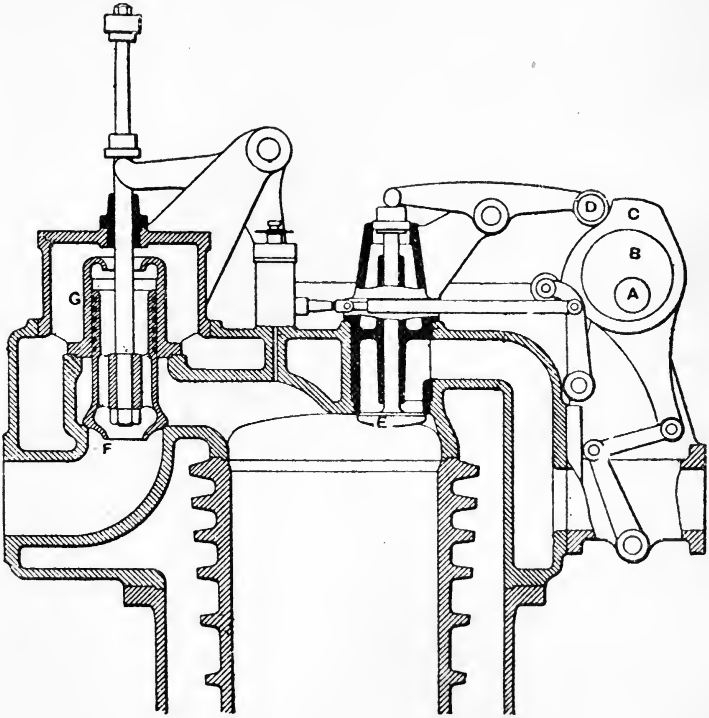


FIG. 7.—Dunlop's Valve Gear.

actuates upon one end of a bell crank lever, the other end of which presses the valve open. The camshaft or half-time shaft rotates at half the speed of the crankshaft, so that the valves open at their proper time in the cycle. It takes two revolutions to perform one cycle of operations, so that the exhaust valve only has to be lifted once in two revolutions. By making this operating shaft proceed at half the speed of the crankshaft, the engine makes two revolutions every time the mechanism operates. This can be accomplished in two ways, one by means of gear wheels, that on the crankshaft having half the number of teeth of that on the camshaft, and meshing into one another, or the valves can be worked by means of a geared eccentric arrangement.

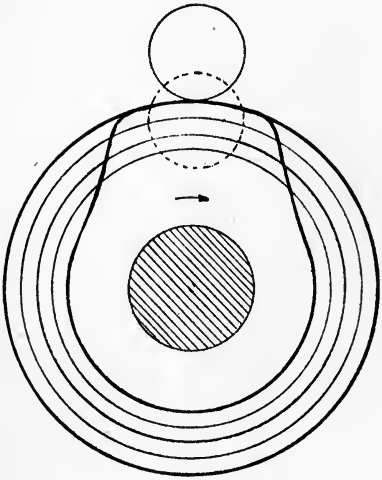


FIG. 8.—The Construction of a Cam.

A cam appears to be a very simple mechanical device, but it must be correctly designed to give satisfactory results. Its object is such as to impart a vertical motion to another mechanism in a direction at right angles to its own axis of revolution. In order to set out a cam for cutting, it is necessary to know exactly the amount of vertical motion to be imparted, and the duration of that motion relatively to the rate of revolution of the cam itself.

Take now the ideal exhaust cam which, for example, is required to lift the exhaust valve from its seat exactly at the end of one stroke, and to retain it in that position during the next stroke. The valve must then be allowed to return to its seat and remain there during the three other strokes which constitute the cycle. If a disc of metal of the required thickness is now taken, and a hole marked off in the centre to fit the camshaft, the disc, being circular, would impart no motion to a mechanism running along its periphery. Concentric circles should be drawn, say, $\frac{1}{8}$ in. apart and allowing a minimum thickness of metal around the shaft, say, $\frac{1}{2}$ in. The circle which is that distance from the hole represents the zero or base line. Two diameters should now be drawn at right angles to one another, and the quadrants each represent one stroke of the piston.

As we have assumed that the valve has to be actuated for exactly one stroke, this is represented by one quadrant which is chosen.

Next the lift of the valve has to be set out, and supposing this to be $\frac{1}{2}$ in., an arc must be marked across the chosen quadrant $\frac{1}{2}$ in. farther from the centre than the base line, and at each end of the quadrant a pair of leading and trailing lines must be drawn parallel to each other and towards the zero or base line running into it and to the maximum line with easy curves. The metal is then cut away, and it will be seen that a roller running on such a cam will have the required vertical motion imparted to it.

As the internal combustion engine is likely to run a portion of a revolution in the reverse direction when starting, care must be taken not to allow any steep step for the roller to drop down when working, as this can only be negotiated when the roller drops, and will not permit it to rise if the motion is reversed.

In actual practice, valves are not set exactly as in theory, for the exhaust valve opens somewhat before the end of the stroke, and closes a few degrees after the inner dead centre has been reached. The inlet valve also is allowed to remain open for a few degrees after the piston has completed its outward journey on the suction stroke.

Balanced Valves.—Owing to the great effort required to open large exhaust valves, Messrs Crossley designed the balanced type of valve which is a combination of a piston valve and an ordinary mushroom valve.

The pressure within the cylinder is between the piston and the mushroom valve seating, thereby balancing the valve to a very great extent; thus the effort which is required to open the valve is only equal to the difference of the pressure on the two areas. There is one difficulty about that type of valve which has been modified in the later patterns. When the valve is lifted, all the hot gases exhaust round the valve stem which obstructs the passage. A slightly different arrangement has now been made which allows a freer flow for the exhaust.

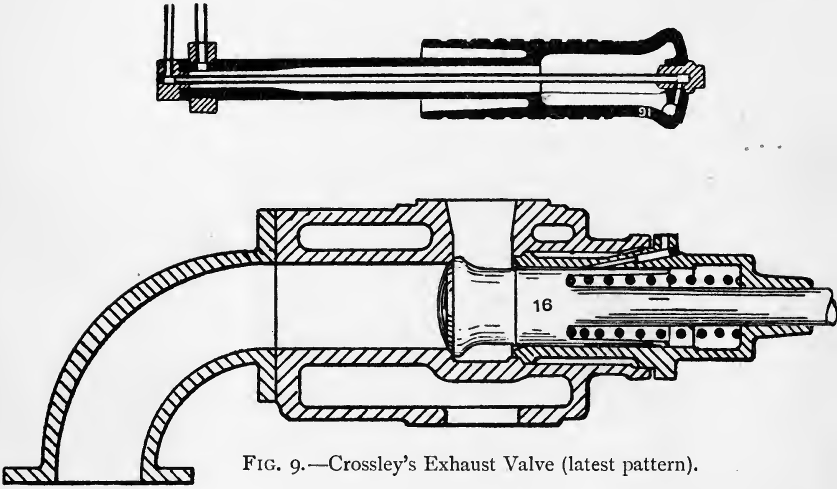


FIG. 9.—Crossley's Exhaust Valve (latest pattern).

In the balanced valve a stream of water is allowed to enter the spindle at the brass cap situated at the end of the spindle. A tube from this point passes right up to the head of the valve. Cold water enters the sleeve and passes up to the valve head, and the hot water returns through an overflow pipe, so that the valve is always kept full of water and thus prevented from overheating.

The diagram shows a modified form of the Crossley valve which is so arranged that the valve when open allows a clear passage for the exhaust gases. In this type of Crossley valve the spindle is not taken across the exhaust port as in the older pattern, but it is somewhat more complicated than the Dunlop valve shown in Fig. 7.

Governing.—Although the Otto hit-and-miss system of adjusting the gas supply to suit the load is so extensively used and so thoroughly satisfactory, as far as economical results are concerned, there are a few defects in this method of governing. In the first place, there is no means of adjusting automatically the mean pressure in the cylinder, and consequently the power and speed undergo extreme fluctuations, which are only kept within reasonable limits by extremely heavy flywheels. Running at a quarter load the governor has to decide in one stroke out of eight whether the load has been increased or not, and if the former, the power is at once doubled. There is, therefore, no adjustment within the limits of 100 per cent. If the load increase has been momentary, the engine will at once race.

In order to remedy this state of affairs, the hit-and-miss arrangement has been abandoned by some makers, and a system of adjusting the quantity of mixture admitted for each charge has been adopted. This adjustment of the mixture allows the burning gases to expand to a volume which is greater than their volume at atmospheric pressure before compression takes place. The result of this expansion is a lower temperature of the exhaust and a greater thermal efficiency at all loads except the maximum. It has been stated from time to time that such an arrangement of throttling in the limit or running light causes miss-fires and explosions in the exhaust pipe, &c. When the point of ignition is fixed, sluggish firing does inevitably take place, owing to the reduced compression of the charge. With graduated impulses at constantly recurring intervals of four strokes, and with two strokes out of the four in which to decide the power in the impulses, it is only a matter of the means employed to obtain the successful result in the engine.

The system adopted by the Westinghouse Company throttles the charge during the whole of the suction stroke, and in so doing secures the graduated impulse, but loses the work done in the throttling, and has a further loss in that no provision is made for altering the time of ignition.

Apart from this, the method of governing these engines is admirable. The air and gas are controlled by cocks with graduated pointers, which enables the man in charge to determine exactly the best ratio of air to use to the gas supplied. When the engine is running on a steady load, if one mixing valve lever is moved while the other remains stationary, the regulating valve stem will move up or down as the mixture becomes more or less efficient, indicating that a greater or less quantity is being used. If the gas cock is set, on gradually opening the air valve, the regulator valve will move down until the critical mixture is reached, when it will reverse its direction. Thus the correct mixture is a matter of exact measurement, and not of individual approximation.

CHAPTER V.

STRATIFICATION—THERMAL EFFICIENCY—CAUSE AND EXTENT OF HEAT LOSSES.

WHEN the early experimenters investigated internal combustion engine problems, Otto propounded a theory that an engine working on his cycle was more economical owing to what he termed "stratification."

He had an idea that if a gas, such as air, was admitted into the cylinder for a certain period, that the volume immediately behind the piston would be filled with air, and if another gas is subsequently admitted, the piston at the same time continuing its outward stroke, the volume of the gas entering would not mix with the air homogeneously, but would stratify in the cylinder.

This is termed the stratification theory, and up to quite recently it was generally supposed that stratification actually took place. The point which Otto made was that if he ignited the pure gas near the inlet valve, by the time the explosion reached the centre portion of the mixture it was somewhat weaker. The stratum of air prevented shock to the piston. That theory he firmly believed in, and substantiated by a very simple experiment, which consisted in taking a glass tube and putting a cigarette into the end of it, and fitting a piston. The piston was drawn out, and the smoke from the cigarette followed the piston up to a certain distance. The after part of the cylinder remained clear. That held good when the piston moved at a slow speed. When, however, a piston moves outwards at a high speed, such a theory is exploded at once. The experiment which proved that there was no foundation in the stratification theory was conducted in the following manner:—

A cylinder was fitted with ignition plugs in different places along its side, and firing tried at these various points, and finally right up against the piston; the same results were obtained in each case. Until recently it was generally agreed that there was no foundation for the stratification theory, but for certain purposes this idea is regenerated in modern large engines. The reasons why the Otto cycle is economical are, in the first place, that the engine forms its own pumps, and has only two valves, and it is evident that the friction in this arrangement must be less than the friction set up in a system of pipes, air compressors, and all the attendant mechanism. The Otto cycle is economical primarily owing to its simplicity. The progress which has been made in the internal combustion engine is represented roughly in these figures.

Fifteen years ago the thermal efficiency of a gas engine was about 16 per cent. Now, at the present time, a thermal efficiency of 30 per cent. is not at all uncommon, and during some recent experiments carried out by the Birmingham University a thermal efficiency of 41.5 per cent. was obtained with an abnormally high compression.

Mr Dugald Clerk experimented in the early days, and found that only from 50 to 60 per cent. of the total heat which was contained in the gas was evolved at the point of ignition, and that 40 or 50 per cent. of the total heat was unaccounted for, and could not be traced at all. In testing gas engines it is noticeable that from a large engine a greater thermal efficiency is obtained than from a small one. The reason for this is discussed under the heading of heat losses. The Otto cycle, in addition to being efficient on account of its simplicity and absence of valves, is also efficient from another cause, which is that there is no loss from interchange of heat in any part of the working cylinder.

When air or any gas is compressed, a certain rise of temperature takes place. This is illustrated in a bicycle tyre pump, or any simple air compressor. The Otto engine draws a mixture of air or gas into the cylinder, which gas is then compressed, and a certain amount of heat is concentrated in the compression space, a portion of which heat is taken up by the cylinder walls, raising their temperature.

It is quite conceivable that if a cylinder full of mixture at a certain temperature (T) is taken when the mixture is compressed, the temperature rises, and there is an interchange of heat between the two bodies—a cold body of iron and a hot body of gas. The iron will absorb a certain amount of heat, and the temperature of the gas will drop in accordance with the rate of interchange of heat between the gas and the iron. Supposing, now, that the cylinder wall temperature is 80 degs. Cent., which is about normal, and a temperature which we assume to be the same as the temperature of the water which is in the jacket.

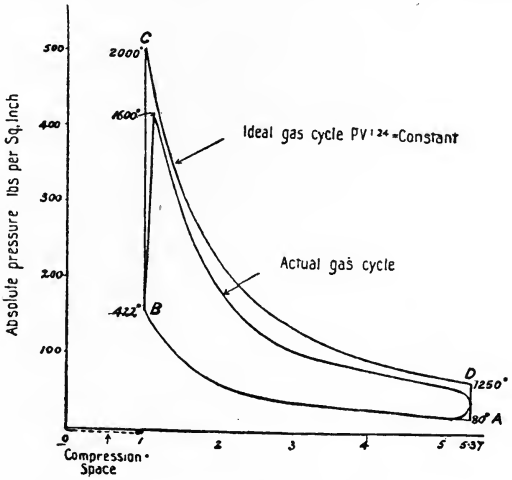


FIG. 10.—Temperatures in Degrees Centigrade.

Referring now to Fig. 10, the point A represents the position at the end of the suction stroke, where the temperature of the mixture in the cylinder is equal to the temperature of the cylinder walls, viz., 80 degs. Cent. Starting at A the mixture of gas and air is compressed to B, the piston doing a certain amount of work on the gas so that the internal energy of the gas at B is greater than that at A by an amount equal to the work done. The rise of temperature due to the compression brings the temperature before firing to 422 degs. Cent. Now at B the mixture is fired and the internal energy of the gas is increased by the whole heat value of the gas until the point C is reached theoretically at a pressure of 506 lbs. per sq. in., and with a temperature of 2000 degs. Cent. Now if a curve of adiabatic expansion is drawn making $PV^{1.24} = \text{Constant}$, expansion would occur along this line to the point D, and the temperature would fall to 1250 degs. Cent. In actual practice, however, the indicator diagram falls within these limits, and for the above compression ratios the firing temperature would rise to 1,600 degs. Cent., and heat would be lost to the cylinder walls, causing the actual expansion

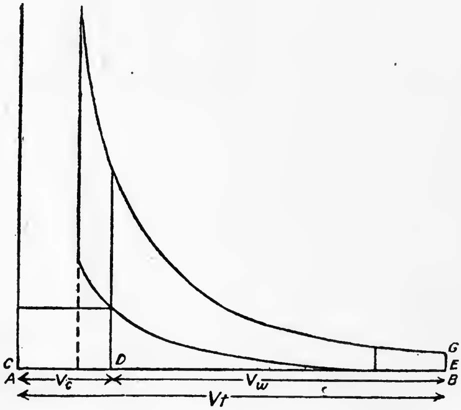


FIG. 11.

curve to fall below the theoretical curve shown in the diagram.

The actual compression ratio is indicated in the above diagram, where AB represents the base line or absolute pressure, its length V_t represents the total volume of the cylinder which is the sum of the clearance volume V_c and the working volume V_w. When the piston is at the outward end of its stroke, the object of the engineer is to fill the cylinder with an explosive mixture of as great a weight per unit volume as possible. This means that the pressure must be as high as possible, and the temperature as low as practical limits will permit. The efficiency of the system depends on the maximum amount of fuel possible being efficiently burnt in unit time. In this respect the action is similar to the combustion of coal in a boiler furnace.

Now referring to diagram (Fig. 10) the ideal curve of expansion is shown where $PV^{1\cdot24}=C$, but if the mixture were a perfect gas it would obey Boyle's law were $PV=C$, and for the present purpose we will assume that it is a perfect gas, and knowing the pressure and volume at any time and the temperature we can calculate any of these values when the remaining two are known, from the equation $\frac{PV}{T}=\frac{P'V'}{T'}$, &c., where P and T are absolute pressure and absolute temperature in every case.

As showing the effect of varying the ratios between V_c the clearance volume and V_w the working volume, the table on page 42 is worthy of careful study. The results are those obtained by the Gas Engine Research Committee with a special engine.

These results on a special engine vary somewhat owing to the variation in the timing of the ignition in different trials, but in the ordinary commercial gas engine when using coal gas the following relations approximate. Where the compression pressure is 90 lbs. per sq. in. above atmosphere the firing pressure will be about four times that amount or 360 lbs. per sq. in., and the mean effective pressure will be about equal to the compression pressure above atmosphere.

Compression Pressure. Lbs. per sq. in.	Firing Pressure. Lbs. per sq. in.	Mean Effective Pressure. Lbs. per sq. in.	Thermal Efficiency.
154	309	82	40.4 per cent.
159	408	106	
166	388	110	
158	334	93	
129	430	114	35·9 „
137	311	93	
129	354	113	
132	309	86	
132	414	106	34·5 „
124	330	82	
124	358	94	
88	341	100	30 „
87	270	88	
87	228	72	

Now if in any particular case a total cylinder full of mixture is compressed into a third of its original volume, a mean pressure of approximately 97 lbs. per sq. in. results, and a maximum pressure of 287, which gives on the indicator diagram a corresponding area. If the compression is carried still further, say to 100 lbs. per sq. in., a higher pressure of firing results, giving a higher mean pressure of 100 lbs. per sq. in., and the increased area of the diagram is obtained as a reward for the increased compression, but no more gas is used in obtaining this extra work. Again compressing up to 140 lbs. per sq. in., the firing pressure is increased to 500 lbs. per sq. in., and the mean effective pressure to 105 lbs. per sq. in., representing the increase of work which it is possible to obtain from an

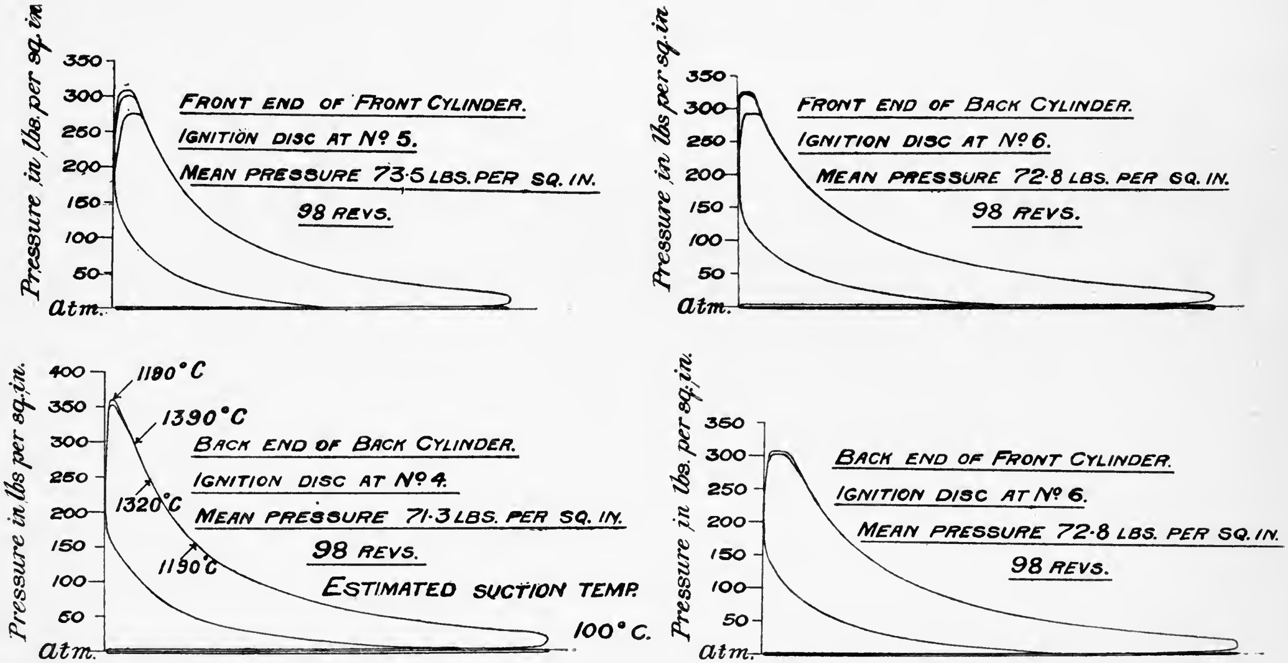

Pressure in lbs. per sq. in
350
300
250
200
150
100
50
atm.
FRONT END OF FRONT CYLINDER.
IGNITION DISC AT Nº 5.
MEAN PRESSURE 73·5 LBS. PER SQ. IN.
98 REVS.
Pressure in lbs per sq. in
350
300
250
200
150
100
50
atm.
FRONT END OF BACK CYLINDER.
IGNITION DISC AT Nº 6.
MEAN PRESSURE 72·8 LBS. PER SQ. IN.
98 REVS.
Pressure in lbs per sq. in.
400
350
300
250
200
150
100
60
atm.
1190° C
1390° C
1320° C
1190° C
BACK END OF BACK CYLINDER.
IGNITION DISC AT Nº 4.
MEAN PRESSURE 71·3 LBS. PER SQ. IN.
98 REVS.
ESTIMATED SUCTION TEMP.
100° C.
Pressure in lbs. per sq. in.
350
300
250
200
150
100
50
atm.
BACK END OF FRONT CYLINDER.
IGNITION DISC AT Nº 6.
MEAN PRESSURE 72·8 LBS. PER SQ. IN.
98 REVS.

FIG. 12.

engine. As the compression is increased only by a small amount, the firing pressure increases by a very large amount. The increase in the firing pressure is about four times the increase in the compression pressure. See Fig. 11.

There is evidently some practical cause for the limitation of this increase of compression, in addition to that of cylinder strength. It is pre-ignition that limits the point to which an explosive mixture can be compressed before firing.

The first law of thermo-dynamics states that heat and work are mutually convertible terms, and Joule's equivalent, which was first determined by him in 1843, is now reckoned as 778 ft.-lbs. being equal to 1 B.Th.U. It is inconceivable, however, that there will be no loss in the conversion, as heat always passes from the hot body to the cold body, and the thermal efficiency of the engine is the ratio of the heat which is converted into work to the total heat which enters the engine.

Now the effect of change of volume and pressure of a gas is demonstrated by Boyle's law, which has been referred to as $PV = C$, when the temperature remains perfectly constant.

Charles' law states that if a gas is kept at constant volume and is heated the pressure increases, and if the gas is behind a piston which is free to move, the pressure being kept constant, expansion will take place.

One volume of gas at 0 deg. Cent., if heated through 1 deg. Cent., will expand $\frac{1}{273}$ of its volume if the pressure is constant. If the volume is constant the pressure will increase by $\frac{1}{273}$ if it is a perfect gas. The absolute temperature of a body is its ordinary temperature Centigrade +273 degs. By this law the relation $\frac{PV}{T} = \text{Constant}$, holds good where P and T are absolute pressures and temperatures, the latter being taken as that of the jacket water. The following temperatures are likely to be obtained in actual practice :—

Firing, 1600 to 2000 degs. Cent.

Cylinder walls at 0.3 stroke = 977 degs. Cent., at 0.8 stroke = 714 degs. Cent.

Distance $\frac{1}{2}$ in. from walls, 0.3 stroke = 1100 degs. Cent., at 0.8 stroke = 765 degs. Cent.

If the temperature is known at the end of a stroke it is quite easy to calculate, from the previous reasoning, the resulting temperature if compression is carried out to any further degree which is limited by the gaseous fuel to be used. A rich gas, such as coal gas, will fire at a very much lower temperature than a poor gas. The diagram shows clearly when pre-ignition occurs. The ordinary compression should be carried on until the temperature rises to a point which corresponds to the degree of compression which can safely be put upon the mixture. Assuming that there is no foreign matter in the cylinder, this pressure is an absolutely definite figure.

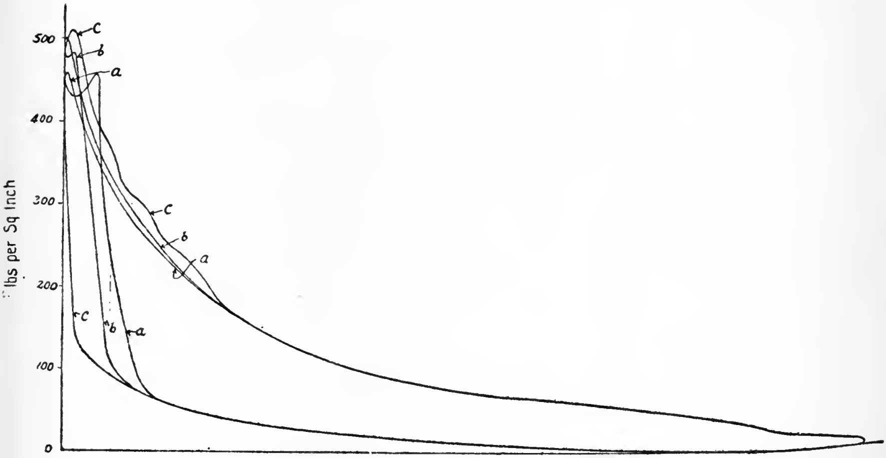


Fig. 13.—Pre-ignition.

If the cylinder could be filled with a perfectly cool mixture the compression could be carried up to a known point, but instead of the cylinder walls being perfectly cold they are at a temperature of 80 degs. Cent., so naturally the walls have a great influence upon the mixture. Instead of filling the cylinder with mixture at atmospheric temperature we generally find that the temperature, when the cylinder is full of mixture, is roughly equal to the wall temperature which is from 80 to 100 degs. Cent. That figure has a material effect upon the thermal efficiency of the engine. The rise in temperature when the gas enters the cylinder represents 10 per cent. of loss in total thermal efficiency.

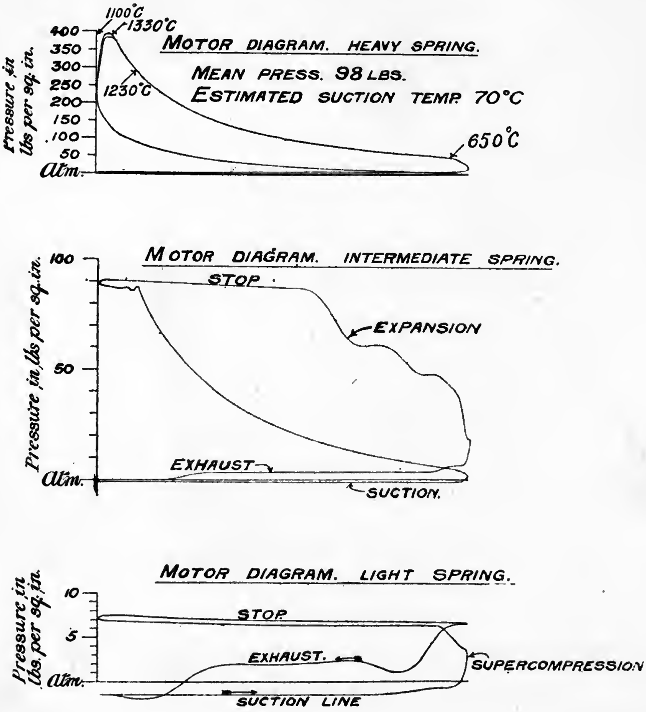


FIG. 14.

There is another feature which also limits the work which can be done by an engine of the Otto cycle, and that

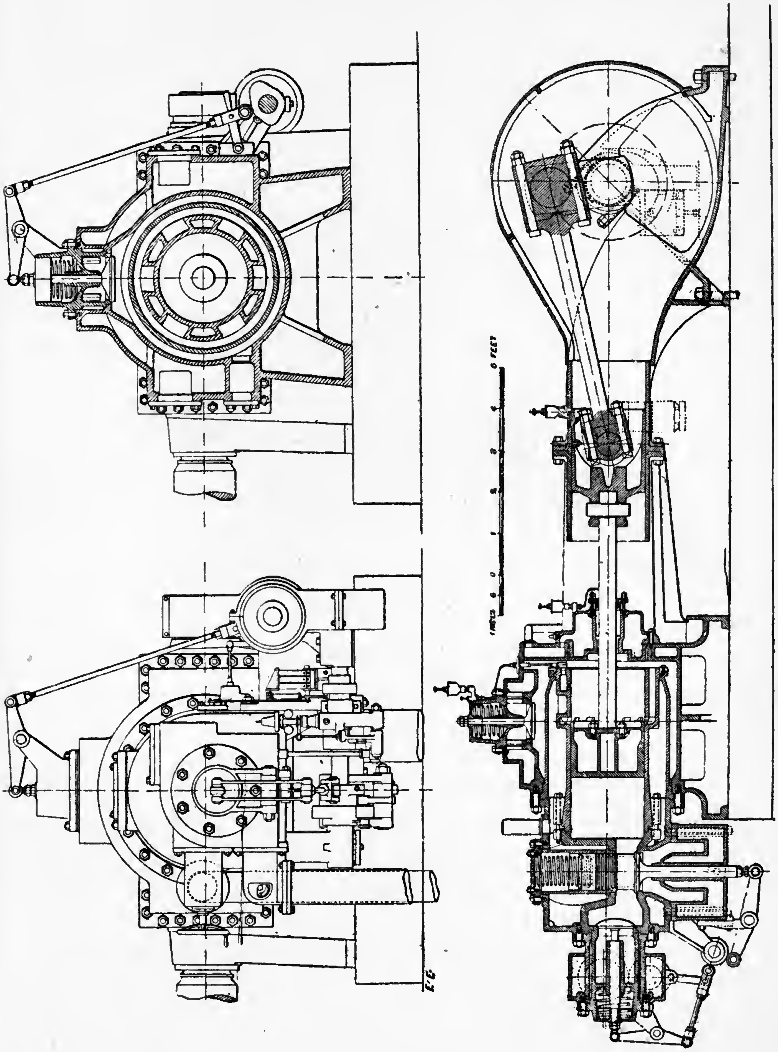


FIG. 15.—Clerk's Super-Compression Engine, from which Diagrams Fig. 14 were taken.

is the pressure of the mixture at the end of the suction stroke. The differences of pressure are shown in the diagram, which represents the indicator card taken with a light spring showing about 1 in. on the indicator diagram for about 10 lbs. pressure. In order to find out the line of the suction a light spring card must be taken. A line below the atmospheric line represents, by its distance from it, the pressure at which the mixture enters the cylinder. It is the designer's object to get the mixture into the cylinder at atmospheric pressure.

The diagram given by a light spring shows firstly the exact position when the exhaust valve opens and the pressure of the gas at that moment. It also shows, by the rapidity or otherwise of the fall of pressure, whether the gas has a free passage to its outlet, whether the valve is of sufficient dimensions, or if there is an obstruction in the silencer or pipe. If the exhaust line falls much below the atmospheric line at the termination of its stroke, the passage is free, and the gases have a good deal of inertia which might assist the cleansing of the cylinder of burnt products when the inlet valve opens. Considering the outward stroke of the piston, the suction line will gradually fall below the atmospheric line, but with valves of ample dimension should rise again to meet it at the end of the stroke, thus ensuring the cylinder being filled with mixture at atmospheric pressure. In a high speed engine it is difficult to attain this, and in order to utilise the inertia of the incoming mixture in the pipe, the inlet valve is held open some 10 degs. after the dead centre has been reached, allowing air and gas to flow in after the compression stroke has really commenced.

The two factors which come into play before the compression can be determined are (1) the suction pressure, and (2) the temperature of the mixture before compression. Knowing these, one can calculate the final compression which can be put upon the mixture safely, and the higher the compression the greater the efficiency. A rough casting or a porous casting would upset the calculations, because any projection on the cast iron, any excessive temperature of the cylinder end, the piston head, or of the exhaust valve will cause conditions which cannot be accounted for; a roughness will in itself cause pre-ignition.

Pre-ignition is due:—

1. To incandescent particles of metal.
2. Porous surface of metal.
3. A heated piston, overheated exhaust valve, and carbon deposits in the cylinder or on the piston.

Prevention of overheating by water circulation has been explained with the arrangements for its supply to the piston, and also to the exhaust valves in addition to the water-jacketed cylinders. Actual test figures show that in an ordinary small engine the temperature of the piston head reaches about 400 degs. Cent.

In a large engine 700 degs. Cent. is about the usual temperature. It is quite obvious that the limiting point for compressing the mixture depends upon the temperature of the piston end and on that which the exhaust valve reaches. The exhaust valve is in the presence of flame every time it opens.

This question of pre-ignition is not very important in the small engine, because the amount of gas which pre-ignites is small. The piston is small, and the parts are made amply strong to withstand any shocks which can come upon them, but with a large engine it may be a serious matter if pre-ignition takes place. The normal point at which true ignition takes place is at the inmost piston position, and the rise of temperature and pressure occurs at constant volume. When the piston is at the inward position of the stroke, the volume is the compression volume of the gas—this is a constant volume when the charge is rapidly fired—giving an uprise of the temperature, represented by a straight line on the indicator card. If from any cause the gases fire before the state of constant volume is reached, there is a rise of temperature and pressure at some point when the piston is coming inwards to the end of its stroke. The volume is decreasing, and the crank is coming round to its inward position. Undue stress comes upon the whole of the mechanism of the engine, because when the piston is coming round to its inward stroke a sudden explosion is liable to reverse the engine, and enormous stresses come upon the crank and crankshaft.

Considerable loss as well as overheating results from sluggish ignition, as when such is the case the piston is moving outwards, and the heat is not added at constant volume. The diagram represents the state of affairs which occurs when the proportions of air or gas are varied in order to govern the engine; the curves are for mixtures at atmospheric pressure, and the proportions have been varied. Naturally, the highest efficiency curve which can be obtained for an indicator card is a curve which gives the greatest rise of temperature in proportion to gas used. As the proportion of gas decreases, the mixture is very sluggish in firing.

A curious phenomenon occurs when the mixture is compressed; before compression it probably will not fire at all. Instead of the maximum efficiency occurring at proportions of 1 to 5, and falling off, when the gas is compressed the maximum efficiency occurs with about 1 to 10 mixture, so that the compression again shows an economy, because it makes the mixture, which is really too weak to be efficient at ordinary pressure, the most efficient mixture in working under compression. There are two facts, therefore, which come into play when utilising compression. The useful work which can be obtained from a given volume of gas is increased, and secondly the gas can be diluted with practically twice its volume of air.

The question of the heat losses in an internal combustion engine cylinder have been very carefully investigated by Mr Dugald Clerk, who has found out the laws which govern the heat flow to the cylinder walls. His unit for the purpose is a "cubic foot degree," which is the amount of heat which one cubic foot of burnt mixture loses in cooling through one degree. He has found by experiment that in one twentieth of a second 20 cub. ft. degs. are lost to each square foot of exposed wall surface, or 400 cub. ft. degs. per second to each square foot of wall surface: A loss of heat takes place to the walls during compression and firing of the charge, causing the temperatures to rise below their theoretical value as shown in Fig. 10, the amount of heat so lost depending upon the rate of revolution of the engine, or in other words, a time element.

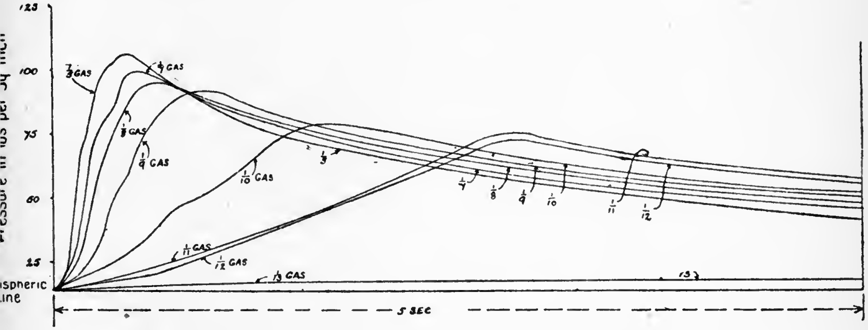


FIG. 16.—The Explosion of Gaseous Mixtures at Atmospheric Temperature and Pressure.

A portion of this heat returns from the skin of the walls to the mixture during the expansion stroke, making the curve of expansion in some cases rise above the adiabatic curve when at about half stroke.

The original German theory for this phenomenon was that an "after burning" or retarded combustion took place, and that at the time of ignition the whole of the mixture did not fire at once. This was originally attributed to stratification. Modern investigations of Mr Dugald Clerk have clearly shown that the intercharge of heat theory is more probably correct. This investigator had an engine specially arranged so that the inlet and exhaust valves

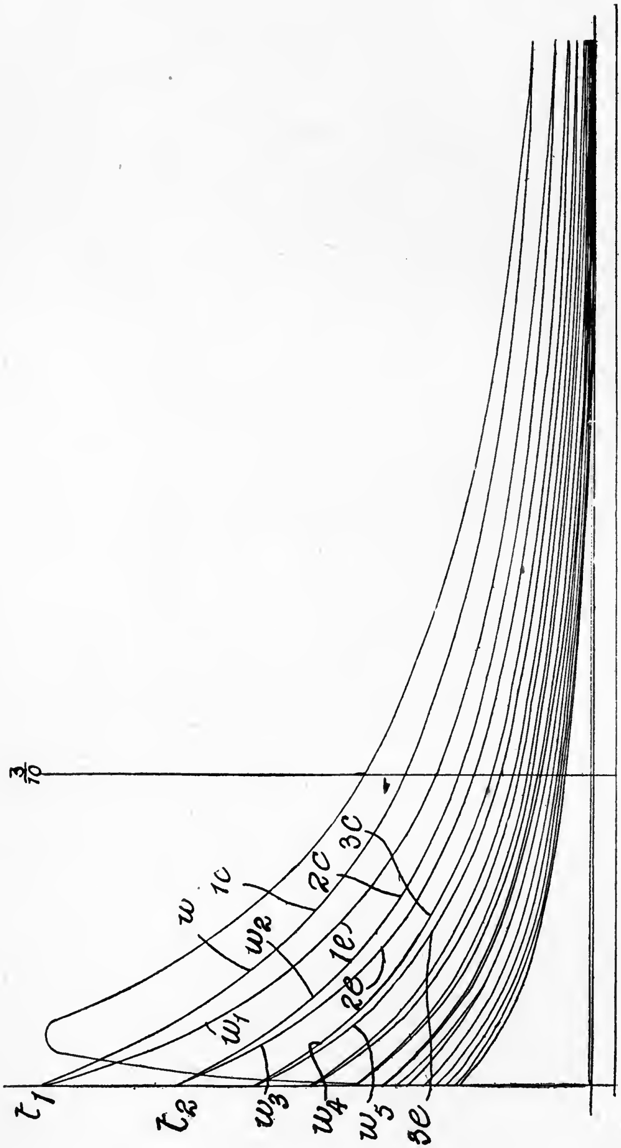


FIG. 17.—Clerk's Cooling Curves.

could be put into or out of action at will, by means of sliding the cam rollers away from the cams. He then ran the engine in the ordinary way, firing under its usual conditions. At any predetermined speed he slid the rollers out of gear immediately a charge fired, and allowed the engine to revolve under the momentum of the flywheel. The action was to obtain an explosion and expansion stroke, and then to continue compressing and expanding the hot gases, which gradually lost a part of their heat to the cylinder walls. The diagram, Fig. 17, shows graphically the rate of loss of heat, as the indicator draws lines representing alternately compressions and expansions; the fall of pressure and consequently temperature is clearly shown at the inward dead centre, these losses being greater at the higher temperatures, and less as the gases cool down. There is, in addition to the loss by cooling, a drop of pressure corresponding to the work done by the expanding gases.

CHAPTER VI.

TESTING OF GAS ENGINES AND CALCULATIONS OF RESULTS.

WHILST numerous inventors are devoting their energies to the improvement of mechanical details, the arrangement of cylinders and valves in order to improve the mechanical efficiency, there is still a great opening for improvements in this particular type of engine in the utilisation of the heat; in other words, to improve the thermal efficiency of the engine.

In a steam engine this would represent the ratio of the total heat in the coal to the total work given out at the flywheel. When testing an engine, it is advisable to approximately anticipate the result before the actual test is completed, so that no slight error in calculation will lead to a great discrepancy in the result, such as the misplacing of a decimal point.

There are several kinds of tests which can be carried out with a gas engine, and details previously required depend upon the results which are aimed at. Generally speaking the following measurements must be taken.

The diameter of the cylinder and the stroke must be measured. These two measurements should be taken in every case and compared with the dimensions given by the maker of the engine. They vary sometimes to an appreciable extent. The diameter of the cylinder is taken by callipers, but in the case of a gas engine this is sometimes a difficult matter as the connecting rod comes right in the centre of the bore, so some care must be exercised to measure correctly.

In testing an engine for thermal efficiency or for the majority of useful tests, it is most important to know the volume of compression space, so that in all but the most rudimentary tests the volume of the compression space should be measured. For this purpose, means must be resorted to which are not the ordinary ones of determining the linear measurements, the best method being by the use of a liquid. In order to prevent leakage certain precautions must be taken, and to prevent any flow past the piston, well oil the piston rings or grease them with tallow. It is as well also to take the valves out and cover them with tallow or white lead. Remove the cover from the top of one of the valves, and knowing beforehand approximately the volume of water required, that quantity should be handy and measured out. As quickly as possible pour into the top of the cylinder the measured quantity of water. Fill up till the water reaches the level of the cap base. Some of these caps have the base projecting some distance into the cylinder, so careful observation must be made as to when the exact quantity of water has been poured in. This projection of the cap is to reduce the compression space, so that the liquid should not be filled up to the top of the cylinder if the cap has a long projection. The measured volume of water which the compression space will hold is therefore the exact volume of the compression space.

If the test is for a scientific purpose it is of importance that the instruments are correct, and they should be all calibrated before and after the test by an independent party. This will afford some protection should any dispute arise as to the accuracy of the test.

Indicating.—With regard to indicating a gas engine, those indicators fitted with external springs are the best type to use. Owing to the high temperatures which occur in a gas engine, the spring works more accurately at an ordinary atmospheric temperature than if exposed to the heat of the burning gas, and a special indicator for gas engines is now made. The indicator diagrams previously referred to, and shown on Fig. 14, were taken with three different strengths of springs. In an ordinary gas engine it is necessary to take two different strengths of springs—a strong spring from $\frac{1}{150}$ to $\frac{1}{250}$ scale to show the card of the working stroke, and a light spring to ascertain whether the valves are correctly set, and also to observe the flow of the inlet and exhaust, as explained in the previous chapter. A thermal efficiency test determines how much heat goes into the engine, how much heat appears as work, and what happens to the rest of the heat; so the first measurement is the calorific value of the fuel, which means the heating value of the gas or the number of pounds of water that it will raise through a certain number of degrees of temperature when burnt with 100 per cent. efficiency.

In sampling a gas the same procedure has to be adopted as in sampling coal. It is always well to take a number of small samples throughout the whole test.

Sampling.—In a steam engine test—and these remarks equally apply to a gas engine trial when a producer is used—the chemist requires a very small sample of probably a number of tons of coal. Haphazard sampling from coal heap will only, by the merest chance, give a correct sample. Take, say, half a ton of coal and put it out on a large plate, spreading it quite evenly, and divide it out into four portions. Remove two opposite quarters, and the two quarters left are then to be broken up, crushed out, divided up into four again, and opposite corners taken away as before. This process is repeated again and again until only a small quantity is left which should be crushed into powder.

Now in taking a gas sample, a similar series of operations must be gone through. In the top of a bottle insert two tubes—one long, the other short. The short tube communicates with the gas-pipe. It is quite easy to trap a small quantity of gas from time to time by releasing the long leg of the syphon. Gas then enters the bottle in small quantities over a long period of time. When using producer gas it is most important to sample throughout the whole trial. Producer gas varies enormously from moment to moment, so that in running a trial with producer gas it is most essential to carry out a sampling arrangement as explained. It is much the best to have the gas reported upon by a chemist, who will give a detailed analysis showing the exact composition and proportion of each constituent which appears in that gas.

When dealing with thermal values, there are what are known as the higher and the lower value. In the majority of engineering practices when a gaseous fuel is converted into another form, as when gas is burnt, and from this gas a certain quantity of heat is evolved, a combination of hydrogen and oxygen takes place, and it depends upon whether the resultant leaves as steam or water as to the exact calorific value obtainable. A chemical combination takes place, and water is formed, if the water leaves as steam it carries away its latent heat with it, and the corresponding number of thermal units are of no use to the engineer for the purpose of doing work. If the latent heat of the steam is included, the apparent value of the fuel is higher than the amount of heat which can actually be obtained from it. If, however, the gas is condensed to water it gives up this latent heat.

In these calculations the lower value is always assumed. If the hydrogen and oxygen come away as water, and this water is cooled to 60 degs. Fahr., the following is the result:—1 lb. of hydrogen condensing with 8 lbs. of oxygen gives 9 lbs. of steam produced. That 9 lbs., multiplied by the latent heat of steam—that is 966 thermal units per pound $+ 212 - 60$, assuming the water comes away at 60—is equal to roughly 10,000 B.T.U. per pound of hydrogen.

That is the figure which represents difference between the higher and the lower values in gas engine trials. Owing to the moisture being carried away by the exhaust in the form of steam, the lower value only is available.

The indicator card of the gas engine differs from the indicator card of the steam engine. It is most important to remember that in a gas engine the indicated horse-power does not depend upon the number of revolutions when working out the usual formula, $\text{I.H.P.} = \frac{\text{PLAN}}{33{,}000}$, which gives you the ordinary steam engine formula for single acting engines.

In a gas engine the number of *working* strokes must be taken which, if the engine is firing in the ordinary way, and not missing, is half the number of revolutions. For ordinary commercial purposes, any area enclosed in the loop of the diagram is not deducted from the power area. If, however, the engine works with air and gas pumps, as in the case of the ordinary two-cycle engine, the exact amount of work done in the pumping strokes must be subtracted, which in some of the large engines amounts to quite a considerable proportion of the power developed. For instance, a Körting engine which has a B.H.P. of 341, requires to have an I.H.P. of 540 to overcome the necessary resistances, so the difference between the two represents the work performed by scavenging or pumping into the cylinder added to the usual mechanical losses.

To find the B.H.P. the ordinary practice in testing large gas engines is to employ an electric brake, such as a dynamo, dissipating electrical energy into a resistance or performing other measurable work. This is more accurate in its determination than a friction dynamometer, and can be more easily regulated. The efficiency of the dynamo must first be known or computed, which can be done to within the limits of practical requirements.

Rope Brake.—It is quite customary to test small or medium horse-powers by means of a friction brake, the most reliable type of which is the rope brake. This may embrace either half or the whole circumference of the brake drum or flywheel as the case may be. The brake horse-power is absorbed by friction between the rope and the drum, the work done being equivalent to lifting the net weight on the tight side of the rope through a distance equal to the distance the weight would have travelled had there been no slip between the rope and the drum. Let the weight on the tight side of the rope $= W$ (lbs.) and the reading of the spring balance fixed on the slack end of the rope $= w$ (lbs.)—these weights must include such details as the hook or pan in the case of W which is used for the fixing of the weight, and also the difference in the weight of the loose end of the rope which does not embrace the drum. The net weight therefore $= W - w$ lbs.

If $D =$ the diameter of the drum in feet,
$d =$ the diameter of the rope in feet,
$\pi = 3.14$,
$N =$ number of revolutions per minute of the drum,

then the distance through which the weight would be lifted in one minute

$$= \pi(D + d)N \text{ feet, and the B.H.P.} = \frac{\pi(D + d)N(W - w)}{33{,}000}$$

which represents the total useful work obtained from the engine, and its ratio to the I.H.P. gives the mechanical efficiency of the engine.

Heat Accounts.—In tabulating a heat balance, or from a thermo-dynamic point of view, the B.H.P. is not considered, as *mechanical* losses are concerned in this measure of work done, as well as *thermal* losses.

Supposing now that the total proportion of heat accounted for amounts to 31 per cent., it is the object of the engineer to discover where the remainder of the heat has gone and if possible to devise means of utilising a portion of it, thus increasing the thermal efficiency. There are two great losses of heat—that to the jacket water and the amount rejected in the exhaust. Of these two the simplest is the measurement of the jacket loss, as we are dealing in this case with a liquid of standard specific heat whose temperature is within the range of an ordinary thermometer.

The observations are usually made in English standard measurements, the pound and the degree Fahrenheit.

The most simple method of measuring the quantity of water passing through the jacket is to connect the inlet direct on to the water main, with a tap to regulate the flow of water and a tee piece into which a thermometer can be inserted in a vertical position. The overflow should then be connected so that the discharge can be delivered alternately into two calibrated tanks, a tee piece being inserted for a thermometer observation as near to the cylinder as possible. These thermometers should be in a vertical position, and readings taken every five or ten minutes. The usual temperature of jacket water overflow on test is 150 degs. Fahr., but greater thermal efficiency can be obtained on a short test with a higher temperature than this, although in continued running this might lead to lubrication troubles. In comparing tests it is therefore important to notice the temperature of the overflow in every case.

The observations of heat lost in the jacket water become very simple, entailing as they do the reading at regular intervals of two thermometers, their difference being the rise in temperature of the water, and this, multiplied by the number of pounds of water flowing into the calibrated tanks in unit time, gives the number of thermal units of heat lost to the water per minute or per hour as the case may be.

The quantity of gas used is generally measured by an ordinary meter. There is usually a small index dial on the gas meter which reads in cubic feet and fractions of a cubic foot, and readings should be taken from this dial. This reading must not be confused with any number on the meter as to the capacity of the meter, which has nothing whatever to do with its reading. If the test is to be very accurate, the pressure and the temperature of the gas must be taken also. In order to obtain the pressure of the gas, it is quite easy to fix a U tube to the main near the meter. Fill it with water, and measure the difference in the head in the two legs of the U. The number of revolutions of the engine are taken in the ordinary way by means of a counter. The side shaft, however, only gives half the number, so double the results if they are obtained from a side shaft counter. The readings should be taken every ten minutes.

Take the brake readings, the loads on the brake and on the spring balance, revolutions by the counter, also explosions per minute.

Take indicator cards, and enter the readings upon the back of the indicator cards, also the temperature of the exhaust if possible. It is very often difficult, and generally impossible, to obtain accurately the temperature of the exhaust.

The information to be supplied by the chemist should be somewhat as follows :—

The quantity of air required for complete combustion and the specific heat of the gas.

Specific heat is the amount of heat required to raise a pound of any substance through one degree in any particular scale as compared with water as unity. For example, 1 thermal unit will raise 1 lb. of water through 1 deg. Fahr., but if 1 lb. of gas or iron or lead be taken, the amount of heat required to raise its temperature through the same range will be in proportion to its specific heat.

In heating the gas in any engine cylinder from, say, compression pressure to firing pressure, it is therefore necessary to know the specific heat of the gas. This is a somewhat complex and varying quantity, and it has been found that the specific heat is different at different temperatures. For all practical purposes, however, it may be considered as being 0.259 at constant volume. This means that 0.259 thermal unit is required to raise 1 lb. of gas through 1 deg. Fahr. The specific heat at constant pressure is less than this in the ratio of 1 to 1.4, which is easily understood, for if heat is added at constant volume, and the volume is then allowed to expand until the original pressure is reached, work can be done by the extra heat which is in the mixture, and at the end of the expansion the amount of heat remaining is the same in each case.

The useful amount of heat or calorific value of a gas may be most conveniently reckoned per cubic foot, and taking an average sample whose calorific value is 613 B.T.U. per cubic foot, we have this made up as follows:—

	Calorific Value per Cubic Foot.	Volume per Cent.
CH_4 - - -	405 B.T.U.	41.78
H - - -	114.4 "	39.11
CO - - -	27.7 "	8.22
Olefines - -	65.8 "	2.77
Nitrogen - -	...	8.0
Total -	612.9 B.T.U.	...

This represents the maximum available heat in the gas, and the amount of heat depends upon the proportions of these various constituents, as also does the amount of air which is required for complete combustion.

Working out the results of the trial, we have a clearance volume, say 30 per cent. of the working volume, which has been previously measured by means of a liquid.

Say the total length of the indicator card is 3.5 in. The clearance volume in linear measurement upon the base line represents an extension of 30 per cent. of 3 in., making the total length 4.55 in.

Let the pressure at the end of the suction stroke = 14 lbs. per sq. in., and the temperature of the gaseous mixture = 150 degs. Fahr.

$$\frac{PV}{T} = C, \therefore \frac{14 \times 4 \cdot 55}{(150 + 461)} = 0.104 = C.$$

From which constant, the temperature of the exhaust can be calculated.

Say the exhaust valve opens at 0.9 of the working stroke

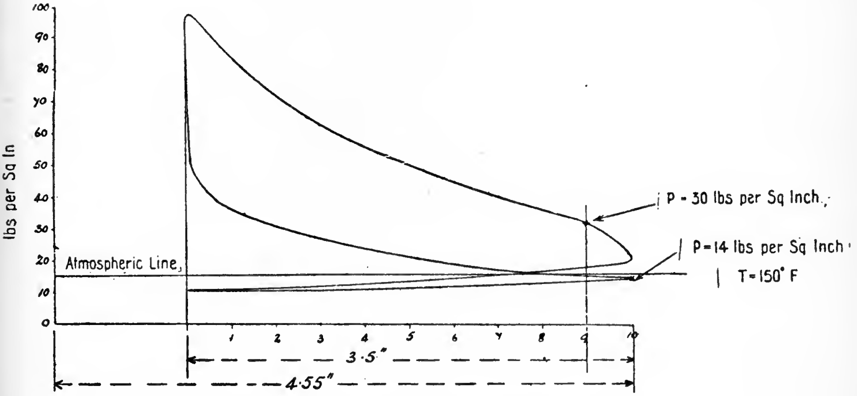


FIG. 17A.—Diagram for Thermal Calculations.

and the pressure at the point of opening is 30 lbs. per sq. in.

The Volume = V when the valve opens

$$= (3 \cdot 5 \times 0.9) + \left(3 \cdot 5 \times \frac{30}{100}\right) = 4 \cdot 15,$$

measured in inches on the diagram as before.

The absolute value of P becomes $30 + 14 \cdot 7 = 44 \cdot 7$ lbs. per sq. in.

$$\therefore T = \frac{44 \cdot 7 \times 4 \cdot 15}{0.104} = 1{,}780 \text{ degs. Fahr.}$$

The heat rejected in the exhaust per minute will be the product of the rise of temperature of the gas, the weight of the gas, and the specific heat at constant volume of the products of combustion.

Knowing the volume of the cylinder, its working volume, and the number of cubic feet of gas used per minute, the total volume of mixture used per minute is equal to the volume swept out reduced to atmospheric pressure and temperature from say 14 lbs. per sq. in. and 150 degs. Fahr.

The gas used is determined by the meter so that the remainder is air, and the ratio of gas to air by volume is at once obtained. The weight of coal gas = 0.0369 lb. per cub. ft. and that of air = 0.076 lb. per cub. ft. at 62 degs. Fahr., so that the weight of mixture passing into the cylinder in one minute can be calculated. But we may take it that the products of combustion have a specific heat of 0.196, but this varies with the proportions of the mixture and its temperature. The heat lost in the exhaust can thus be determined.

The following table gives the losses which occurred in the three engines experimented upon by the Gas Engine Research Committee. The sizes of the engines were: L = 6 I.H.P. with a 5.5 in. diameter cylinder; R = 24 I.H.P. with a 9 in. diameter cylinder; X = 60 I.H.P. with a 14 in. diameter cylinder. These engines were arranged in the same room and supplied with the same gas:—

	L.	R.	X.
	Per Cent.	Per Cent.	Per Cent.
Exhaust waste - - - -	34.1	37.1	39.9
Jacket waste and radiation -	34.1	29.6	25.4
I.H.P - - - - - -	31.8	33.3	34.7
	100.0	100.0	100.0

It will often be observed in a gas engine trial that a reduction in one loss gives a proportionate increase in another, and in the above table it will be noticed that a decrease in the jacket loss with the engine R is accompanied by an increased loss in the exhaust. It will be noticed also that the thermal efficiency increases slightly as the size of the engine is increased.

CHAPTER VII.

GAS PRODUCERS.

Advantages of a Producer.—The term "working fluid" is applied whether the agent be gas or steam or any other substance. In the internal combustion engine, the fuel used must be previously gasified. Certain engines have, however, been constructed to which the fuel has been supplied in the form of dust; this is rapidly converted into a gaseous or semi-gaseous form in the engine itself, but a gas or vapour will always give the most satisfactory results. Starting from the base of a solid fuel, say coal, the apparatus employed is termed a gas producer in which the coal is converted into gas before it is admitted to the engine.

A gas producer performs the same function to a gas engine as a steam boiler does to a steam engine, but it has advantages over the steam boiler. A steam boiler has to be considerably larger than a gas producer for the same horse-power except in the flash generator type. In a steam boiler you have the gas or vapour generated at a high pressure and temperature. The pipes have to be constructed of a suitable size and strength in order that undue friction shall not be set up. In a gas producer, however, the gas is generated at a very low pressure—practically at atmospheric pressure. Thus there is no great risk of leakage through the apparatus or pipes and no difficulty in keeping joints tight.

There is another point which is the effect of condensation. A high temperature and ample insulation must be maintained in the case of steam pipes to prevent an abnormal amount of condensation, but with gas the great point is to keep the temperature of the gas low, so that radiation from the pipes is an advantage. The weight of gas which is contained in any volume depends upon the temperature of the gas at that time, so that if hot gas is drawn into a cylinder, the weight of gas in that volume is less than it would be if the gas were cold.

It is generally advisable in a gas power installation to arrange the producers near the engines, but in some cases this cannot conveniently be done. There is no difficulty in carrying producer gas in mains a reasonable distance, such as half a mile, and this has been done in certain cases. When a distance separates a gas-driven electric generator from its point of supply, it is sometimes a question as to whether it is better to convey the gas in a pipe, or to convey the electricity in the usual way by cables. The former system will answer even without the use of gas exhausters, but it has not proved satisfactory over large areas.

Ordinary coal gas is produced by heating coal in a retort with a fire on the outside of the retort, gas is distilled off and is cleaned and purified. This continues until only coke remains in the retort. The action of a gas producer is similar except for the fact that gas is distilled in the same vessel as the fire which supplies the necessary heat.

When coal is burnt on a grate, flame is produced from the gases, which are distilled from the coal by the heat below it, burning with the surrounding air. There is, too, the glowing fuel in the lower part of the fire consuming away without flame. When the fire is thick and contains only glowing fuel, short bluish flames rise from the surface. These flames show the combustion of carbonic oxide, which is generated by the combination of carbon in the upper layers of the fire with carbonic acid rising from the lower part, where combustion has been complete. The addition of fresh fuel causes grey and yellow volumes of smoke to be given off; these gases do not ignite immediately, as the temperature is too low in their neighbourhood, but as soon as the heat increases they burn with yellow flames. In this case the fire below the green fuel produces the gas, and in the same grate, as opposed to the manufacture of coal gas in a separate compartment or retort.

In the case of burning coal directly in the boiler, there are continual variations in the temperature of the furnace, which cause gases of different calorific value to be given off from time to time. These variations are at the root of the smoke nuisance in our large towns, and are also a source of considerable loss to the consumer. If we could keep the temperature fairly constant, and exactly regulate the quantity of air required, we could produce much more satisfactory results.

Gas should be made from the coal in a separate enclosed producer, and be carried by pipes to the place where it is required for combustion. The analyses of gases made in various producers are as follows, in per cent. by volume:—

With steam jet blast, generally used:—

CO	H	CH_4	CO_2	N
23.4	13.8	2.25	4.7	55.85

Fuel used, fine slack.

Working a producer with an excess of steam for the recovery of ammonia the analysis would be approximately:—

CO	H	CH_4	CO_2	N
11	28	2.5	15.5	43

the first three columns showing combustible gases, and the last two inert gases.

The amount of heat in the original fuel which is used to transform it into gas is about 10 to 13 per cent., but this is not strictly a loss due only to the producer, as when the fuel is burnt in the boiler, heat is also required to gasify the green fuel and to raise its temperature.

The Producer to Use.—There are a variety of producers on the market; each has some special feature. Anthracite producers have been used for many years, and have done excellent work at a low cost, the consumption of fuel being under 1 lb. of coal per horse-power hour with gas engines. These producers are very convenient for small powers, but the cost of anthracite rather excludes their use on a large scale. The gas given off is clean and uniform, and is usually generated by means of a superheated steam blast inducing the necessary amount of air. Gas can be made at intervals of about twenty minutes, or continuously, an attachment to the gasholder regulating the supply of steam to suit the load.

This gas is used to a large extent for direct combustion in engine cylinders, and, by means of coke and sawdust scrubbers, is rendered quite clean enough for that purpose. The fuel is washed and fed to the producer in small pieces the size of beans or nuts. The grate bars have to be cleaned and clinkered from time to time. The importance of a good producer and its attachments is, however, most manifest when dealing with bituminous slack. One of the chief causes of trouble has been the amount of tar in the gas.

The type of grate to employ for satisfactory continuous working has received much attention, in order to obtain complete gasification of all the fuel, with a minimum of ash and clinker. In the old types of producer with closed grates there was the difficulty of cleaning and the stoppage of working for that process. Air should be admitted to the centre of the glowing fuel, and permeate in all directions, upwards and sideways, so that there is no green fuel in the vicinity of the grate. If the blast is simply forced outwards to the walls of the producer, clinker is formed where the air impinges, and there is a mass of fuel out of the direct action of the blast. Flat grates have been tried, but these must be freed mechanically from ash by revolving, and there is a risk of good fuel falling through with the ash.

A grate or grid which overcomes these difficulties is made A-shaped, as shown in Fig. 18, and runs across the inside of the producer, having its legs resting on the bottom of a water seal. The whole apparatus is built over this seal, which slopes up to the floor level at the two sides. The fuel proper rests on a mass of ash standing in the

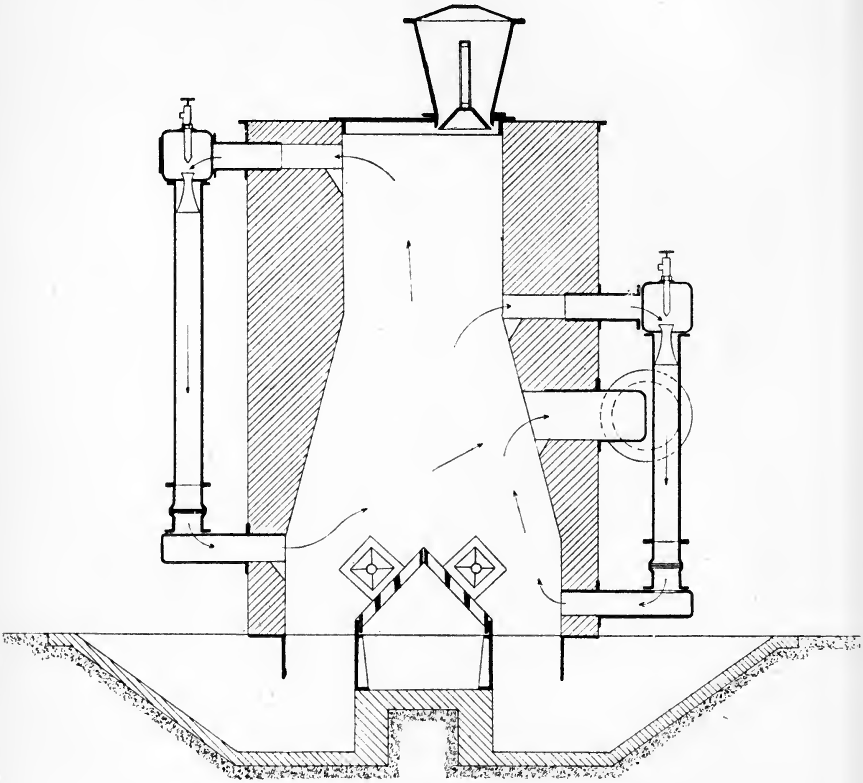


FIG. 18.—Duff-Whitfield Producer.

water seal, the surface of the ash is level with the perforated part of the grid, which is slotted on the two sides at the apex. This grid forms the air distributor, and the blast is supplied at one end; air and steam rise through the centre of the fuel and outwards to the sides. There is thus no portion out of the direct line of blast, with the result that perfect gasification occurs, owing to the large grate area and better distribution. As the working continues, ash is drawn from the water seal, allowing the fuel to sink, fresh coal being fed at the top. With the largest size of grate about one ton of coal per hour can be dealt with. This type of grate is most successful when used in connection with ammonia recovery.

As before stated, gas for firing boilers is not usually cleaned, but for use in engine cylinders, scrubbing and cooling is essential. As the hot gas, at a temperature of about 500 degs. Cent., leaves the producer, it passes through a regenerator, heating the incoming blast. The blast is further heated by passing down an annular casing round the inner shell of the producer. The gases are passed through one or two rotary washers, fans being usually employed, and at the centre of these a water supply enters. This water is dashed about and cools the gas to about 90 degs. Cent., at the same time precipitating tar, which is drawn off. The gas passes upwards through a cooling tower, where it meets a downward stream of water; this water can afterwards be used for heating the blast. Sawdust scrubbers are also necessary, these require cleaning out periodically, as any tar still remaining is deposited here. The gas is then led to a holder and to the mains.

The calorific value of producer gas is about 140 thermal units per cubic foot, but varies slightly under different conditions of working.

Efficiency.—The efficiency of any method of converting heat into work is one of the main points to be studied. A Mond plant of 1,000 H.P. will produce at full load 72 cub. ft. of gas of a calorific value of 146 thermal units per cubic foot from 1 lb. of slack, whose calculated value is 12,200 B.T.U. per pound, while at one-third load the production will be about 71 cub. ft., of a calorific value of 144.5 thermal units per cubic foot. The efficiency of the plant is thus about 86 per cent. when ignoring the heat introduced in the form of steam, but including this the efficiency will come out at about 70 per cent. The comparative cost of fuel for steam engine and gas engine with Mond producer and dynamo driving will be about:—

Cost of fuel per Board of Trade unit, Mond gas, 0.15d.
Cost of fuel per Board of Trade unit, steam engine, 0.22d. to 0.3d.

It will be noted that the gas plant is to the gas engine what the boiler is to the steam engine, and it is even more important to consider the former than the latter, as the gas produced is subject to greater variation in quality than the steam is in pressure. To determine the efficiency of the plant, account should be taken of all the fuel consumed in the apparatus used, and the percentage of the total energy available for the engine calculated. When boilers or fans are used in connection with the gas plant, the energy consumed in each case has, of course, to be considered in the same way as that consumed by the pumps of a steam engine.

In comparing different producers, all results should be brought to the same base as regards temperature and pressure of the gas produced, and the calorific value of the coal from which the gas is derived. Further, it is important that the gas be uniform in quality, and suitably chemically constituted for the work it has to perform, and that these conditions can be maintained for several consecutive hours. Producers should be able to work economically at light as well as at full load. The fact of several generators being worked together does not affect the quality of the gas if the arrangement is suitable, there being many installations of a battery of gas producers in this country.

When large quantities of steam are carried through a generator, it often is a sign that the fire is not dense enough or deep enough for the quantity of steam used. The depth of the fire depends on the size of the generator and nature of the fuel. Some producers have an arrangement to define the active depth of the fuel. A funnel descends from the top of the producer, the green fuel being fed into this funnel. Thus the active depth is the distance from the grate to the base of the funnel, the gas rising from the surface of the fuel around the base of this funnel. With bituminous coal, heavy hydrocarbons are given off when the fresh fuel is put into the generator. It will thus be seen that an automatic feed is desirable for large bituminous producers.

Dowson gives figures regarding the efficiency of his plant, which vary from 79 to 82 per cent. With a heat efficiency of 80 per cent. the losses may be accounted for as follows:—

Loss in boiler	7 per cent.
Steam not decomposed	1 „
Fuel lost with ashes	2 „
Sensible heat of gas lost in cooling, &c., and radiation	10 „
	20 per cent.

The efficiency of the Mond plant calculated to the same basis as the above is 79 per cent.

In the Dowson system, steam or moisture is introduced in order to produce a proportion of hydrogen in the gas. In this system air and steam are blown in, the steam jet acting in the same way as an ordinary injector. By proper regulation of the steam jet, decomposition takes place; this is shown by the fact that the proportion of CO can be reduced, and that of the hydrogen increased, by the admission of steam. In the Mond system, where ammonia recovery is carried on, an excess of steam is admitted and a large amount of CO_2 is produced.

The following table gives comparative gas analyses under three different processes :—

PERCENTAGE OF CONSTITUENTS.

	Coke and Air Gas.	Dowson Gas.	Mond Gas
CO_2 - -	1.6	6.6	16.0
CO - - -	32.3	25.0	11.0
H - - -	4.0	18.7	29.0
CH_4 - -	0.8	0.7	2.0
N - - -	61.3	50.0	42.0
1 lb. carbon is contained in	76 cub. ft. of gas.	93 cub. ft. of gas.	...

The manufacturer of a producer will guarantee that the consumption will not exceed 1 lb. of anthracite per B.H.P. per hour in ordinary working. Anthracite varies in price, but in gas making only 13½ lbs. are used per 1,000 ft. of gas generated, which is equal to a cost of about one penny per 1,000 ft. of gas; and with coal at 12s. to 15s. per ton, this is equal to one-tenth of a penny per B.H.P. per hour for fuel.

About five times as much producer gas would be used as when ordinary coal gas is employed, because the heating value of producer gas is only about 140 thermal units per cubic foot. In a gas engine using producer gas, about equal volumes of air and gas are required for complete combustion.

In gas producer plant there is always difficulty with impurities, which come off in the form of sulphur and tar, and for plants below 500 H.P., anthracite and coke have been used as fuels almost without exception up to the present time.

The effect of these impurities is that when the gas passes along the pipes it deposits tar, which is most injurious, as if it gets into a gas engine it clogs up the valves and piston rings. A large number of patents have been brought out to prevent the tar getting into the engine. Some inventors have adopted systems of fans and water spray ; in one of these systems there is a pair of fans. Water is injected and is dashed about by the fans, this action is said to sweep away any particles of dust or tar which may be in the gas. Notwithstanding this, a large amount is carried forward in suspension in the gas. The more modern idea is to convert the tar, before it leaves the producer, into a fixed gas.

If coke or anthracite is the fuel in use, apertures are made in the producer about half-way up, and at the top an injector is placed on either side of the producer as shown in diagram (Fig. 18). If bituminous coal is used, coal is filled up to a suitable point, and the injectors are put into action ; part of the gas is extracted before it reaches the top of the producer and the remainder at the top. The cooler gas, which is distilled from the top of the producer, is heated up by passing again through the glowing fuel and is taken away at a point about the middle of the producer.

Nothing is gained by taking gas from a hot part of the fuel and returning it at the bottom of the producer, as the whole action depends upon the gas which is cool being taken and heated and the tar thereby converted into a fixed gas.

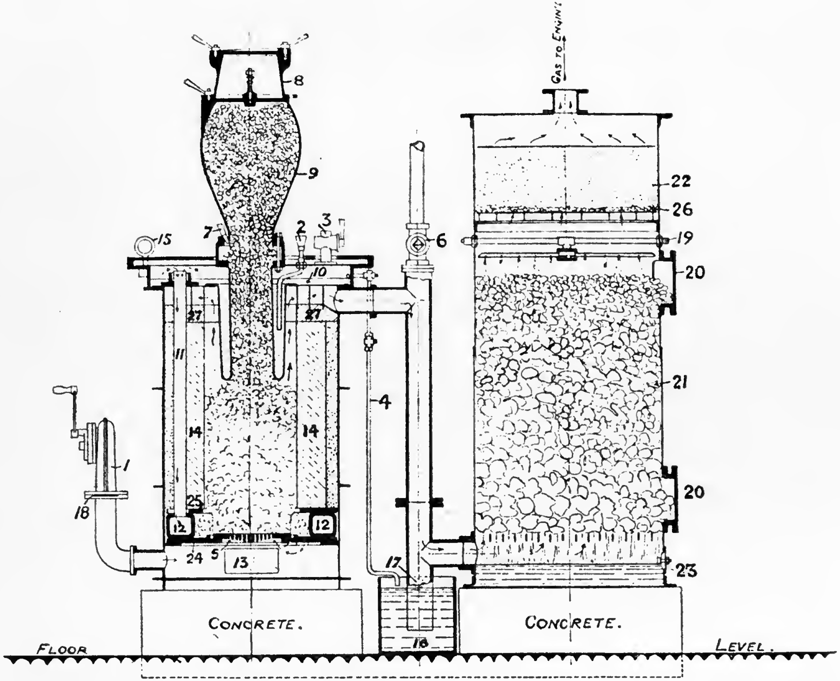
Suction producers have been manufactured in greatly increasing numbers during the past few years and very many installations are now at work with marked success.

The suction system obviates at once the use of a separate boiler, which is required to generate the steam blast in the pressure producer ; it also does not require a gasholder, as the gas is sucked directly by the engine from the producer with only the scrubbing apparatus intervening.

Thus it will be seen that there is no storage of gas, as it is only made as required, and very much less space is taken up by the accessory mechanism. As the suction producer is continuous, as distinct from the intermittent action of the pressure producer, its action is slower and less heat is generated in the producer itself, and consequently less clinker is formed. Variation of load produces fluctuation of draught through the producer, which must be provided for, and the aqueous vapour must be regulated accordingly. The original blowing of the fire is accomplished by means of a fan, and the vapour is produced from a water trough or annular space, which is kept hot by the producer itself and by heat regenerated from the gas on its passage from the producer to the engine. Experiments show that the most suitable temperatures for moisture-laden air are between 52 and 76 degs. Cent., above which too much moisture is carried into the producer. British practice in the design of suction producers gives for a 50 B.H.P. engine, with a piston 15 in. diameter, displacing 2.25 cub. ft., and with a piston speed of 600 ft. per minute, a grate area of 15 in. diameter, which is somewhat larger than the French practice. The depth of the fire is 20 to 24 inches in the larger producers and 15 to 18 inches in the smaller sizes.

Blast furnace gas is one of the enormous sources of power we have in this country which is running to waste. The late Mr B. H. Thwaite originally attempted to use it in 1894, and at the present time upwards of 300,000 B.H.P. is generated from the waste gases of blast furnaces on the Continent.

There are difficulties in the utilisation of blast furnace gas, but they can be overcome. Those particles of dust which are carried in suspension must be extracted from the gas before it can be used in the engines. A few large firms of engineers in the North are making engines for use with blast furnace gas, and in the next ten years we shall no



NO	DESCRIPTION
1	HAND FAN
2	FEED WATER FOR VAPORIZER
3	AIR REGULATING COCK
4	OVERFLOW FROM VAPORIZER
5	FIREGRATE
6	BLOW OFF COCK
7	POKER HOLES AND PLUGS
8	FEEDER
9	HOPPER
10	VAPORIZER
11	SUPERHEATER PIPES
12	SUPERHEATERS
13	FIREDOORS
14	FIREBRICK LINING
15	EYE LIFTING BOLTS
16	SEAL POT
17	OVERFLOW FOR SEAL POT
18	PLATE DAMPER
19	SCRUBBER WATER SPRAY PIPE
20	FILLING DOORS
21	COKE SCRUBBER
22	SAWDUST SCRUBBER
23	CLEANING DOOR
24	FIREGRATE SUPPORT
25	FIREBRICK SUPPORT
26	LAYER OF SHAVINGS
27	FIRECLAY.

FIG. 19.—Crossley Suction Producer.

doubt see the development of this class of engine increasing enormously. From every blast furnace 40 per cent. of the total fuel is being absolutely wasted at the present time. In a blast furnace a certain amount of power is required for blowers and the operating machinery. Of the total gas which is produced, 45 per cent. is absorbed in hot blast stoves and 15 per cent. for blowers, leaving 40 per cent. available for other work.

Having regard to the enormous quantity of fuel used in blast furnaces, the significance of this 40 per cent. of wasted power becomes apparent.

Now, consider for a moment what takes place when coke is delivered into a blast furnace with the iron ore. A portion of the carbon is necessary for the fusion of the ore, the remainder combines with the oxygen in the air and is given off as CO in the combustible gas escaping from the furnace. It is this escaping power which is insufficiently utilised in the ordinary way under a steam boiler, in which with its engine the thermal efficiency rarely reaches 10 per cent.

Large units of power are necessary to deal successfully with this quality of gas, as it is of a low calorific value owing to the absence of any appreciable quantity of hydrogen, and high compressions are necessary in order to ensure the firing of the gaseous mixture.

A somewhat similar by-product to this gas is the gas distilled in a coke oven. When coke is made for smelting purposes a special coal is taken and subjected to heat. The coke that remains is in lumps about the size of a brick and very hard; this is to stand the pressure due to the weight of the material or ore. All the gas is distilled off and the greater part is wasted. From coke oven gas very useful by-products can be recovered. In the old type of bee-hive oven without recovery plant, the escaping gas is another great source of power which is going to waste. In addition to the gas there are very valuable by-products, such as benzol. This liquid is similar to water in appearance and can be recovered at the rate of five million gallons a year from recovery plants now in use with coke ovens, but if suitable plant were put down in many of the older works ten million gallons a year could be recovered at once.

CHAPTER VIII.

OIL ENGINES.

THE use of a liquid as distinguished from a solid fuel was the origin of the production of the oil engine, the fuel in this case being ordinary paraffin. A petrol engine is practically the same as an oil engine, but the difficulty of utilising the liquid paraffin is much greater than is the case with petrol. With a gaseous fuel it is important that certain proportions between the air and the fuel be maintained, and with liquid fuels it is equally important. In the case of gas there is a more easily measurable quantity to deal with, and by using certain sized valves it is a simple matter to regulate the proportions between the air and gas, but in the case of a liquid fuel it is necessary to convert the fuel into gas or vapour before mixing it with its proper proportion of air. Up to the present time makers have brought the fuel in a liquid form to some point near to the engine, and converted it in small quantities in a vaporiser into a gas of a somewhat fixed nature. At each suction stroke it is drawn into the engine as a more or less fixed gas. Very small quantities have to be introduced at a time, because oil increases in bulk enormously when converted into a gas or vapour.

In dealing with such a small quantity of oil it is easy to make an enormous error in the proportion which is required for any particular charge, because the majority of engines only suck one charge at a time into the vaporiser. The proper charge of oil for a 5-in. cylinder is only equal to about one large drop per charge, so that it is important when dealing in small quantities, such as are required by a motor car engine, that the regulating apparatus is extremely delicate. In some types of engine the oil has been varied in its quantity when governing, and consequently from time to time too weak a mixture is formed and the proportions do not come within the limits of combustion. In order to utilise a liquid in the form of oil in the cylinder of an internal combustion engine successfully, methods have been tried to cope with the difficulties present. The fuel can be introduced :—

(1.) As oil, *without* chemical change, either in an atomised or partly vaporised and partly atomised form.

(2.) *With* chemical change, such that the oil before entering the cylinder has been wholly or partially decomposed into the lighter hydrocarbons.

In case (1) may be classed the first commercially successful engine, the Priestman, although in its effect it borders on case (2). The paraffin was injected by means of a nozzle into a chamber on the cylinder head and in direct communication with the cylinder itself. This chamber kept hot, due to the heat of explosion under normal working conditions. The action of the spray being to atomise the liquid fuel, the heat of the chamber and the rapidity of compression converted the spray into a smoky vapour, which burns when mixed with its correct proportion of air. In this type of engine the compression is comparatively small, as a high compression would render the mixture unstable and liable to pre-ignition.

Distinct from this type is the Diesel engine, which works by compressing the air alone up to about 700 lbs. per sq. in. At the end of the inward stroke of the piston the correct proportion of liquid fuel is injected into this highly compressed air by means of air at a higher pressure operating a jet. As this fuel enters the cylinder it burns spontaneously, without a sudden rise of temperature, throughout the greater part of the working stroke.

Finally, there is the Roots type of engine, which has the low or ordinary compression of about 70 lbs. per sq. in., in which each charge of oil is accurately measured, and injected into the engine cylinder during the suction stroke, and in which atomisation is chiefly relied upon to produce proper carburation of the air in the cylinder.

Under type (2) come all engines having externally heated vaporisers, in which the liquid fuel is first converted, by partial decomposition, into a gaseous or semi-gaseous state before its introduction into the engine cylinder. A chemical change takes place in such a vaporiser, and there is always the likelihood of deposits of carbon or heavy residuals forming here. Any possible variation in temperature between the vaporiser and the induction pipe will cause the vapour to condense in the pipe or round the inlet valve before it reaches the engine.

The effect of such an action may not be very marked in a stationary slow-speed engine running at constant load and speed, but when these conditions vary, the whole system may easily become deranged, owing to the small explosive range of a mixture of air and oil vapour ; so that when an oil engine is designed for varying loads and speeds, such as for motor car work, the following points are to be considered.

Fuel Measuring.—The oil-feed must be accurately measured, and be in exact proportion to the air admitted at all times—any system of governing by throttling the air inlet must act upon the feed of oil in the same proportion.

A spray carburetter cannot give satisfaction when oil is utilised, as the action of a jet is not proportional, and there must of necessity be a great variation of the feed in such a device. This variation will occur not only for those working strokes in which the volume of air is reduced by throttling, but also when the throttle is full open and the supply of air unrestrained.

Owing to the small explosive range in the case of oil, either more or less vapour than that required to produce the best results will cause a miss-fire, which will be followed by one or more others, resulting in the stoppage of the engine. Usually about 20 per cent. of the total cylinder volume contains inert or burnt gas at the end of a charging stroke when the engine is firing correctly. But when an explosion is missed, the next charge is richer (perhaps too rich to fire), owing to the absence of this 20 per cent. of inert gas. An absolutely positive, accurately measured and mechanically controlled feed of oil is therefore a necessity in this type of engine, and this feed must be delivered every working stroke. The volume of oil required to carburate free air is so very small (about 2.5 per cent. by volume) that the chief difficulty is encountered in producing an apparatus sufficiently sensitive and at the same time one that will stand the wear and tear to which such an apparatus is subject.

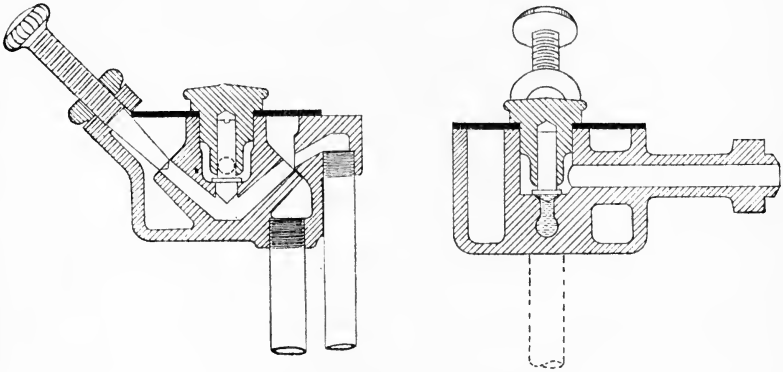


Fig. 20.—Crossley Oil Measurer.

The diagram, Fig. 20, shows the Crossley oil measurer, the **V**-shaped cup being the capacity of the measure, and containing one charge. A pump driven by the engine delivers oil into this cup in very much larger quantities than is actually required, the surplus oil running over and returning to the tank. A small valve is shown, through which the charge of oil is sucked each time the gas valve on the engine is opened. This charge passes round the tubes of the vaporiser and thence to the cylinder. An arrangement of this kind must be governed on the hit-and-miss system, as each charge of oil is of the same quantity, and such an arrangement would not be suitable for varying loads such as are met with in motor car work. Any system for the utilisation of oil, such as paraffin, should proportion the charge of oil to suit the volume of air drawn in.

Since the suction producer has been proved a successful adjunct to a gas engine, it is in the majority of cases to be preferred to the use of oil, with its attendant deposits of tarry matter which require constant cleaning.

CHAPTER IX.

THE PETROL ENGINE AS EMPLOYED IN THE MOTOR CAR.

A STUDY of the previous chapters will make the student familiar with the main principles of the motor car engine, which is the highest state of evolution of the gas engine and the gas-producing apparatus. Until quite recently the gas engine was only developed in the horizontal form, it being always supposed that the difficulties of constructing a successful vertical gas engine were very great. One of the chief of these difficulties was that of lubrication. At the present time, however, there are several types of large vertical gas engines, the pioneers of this type being the Westinghouse Co.

As opposed to gas engine practice, motor car designers very soon discarded the horizontal engine in favour of the vertical pattern, and he is a very bold designer at the present time who markets a horizontal engine. Probably fashion and convenience are the dictators in this matter.

The early cars had almost invariably horizontal engines fitted, and those of the Benz type were very little more than an ordinary gas engine. De Dion was really the pioneer of the type of high speed vertical engine in universal favour to-day.

The old Benz engine was one of the few which would work when motor cars were first permitted on the road in this country after the 1896 Act was passed, and a somewhat similar type to that, more or less a modified form of the existing type of gas engine, was the 5 H.P.

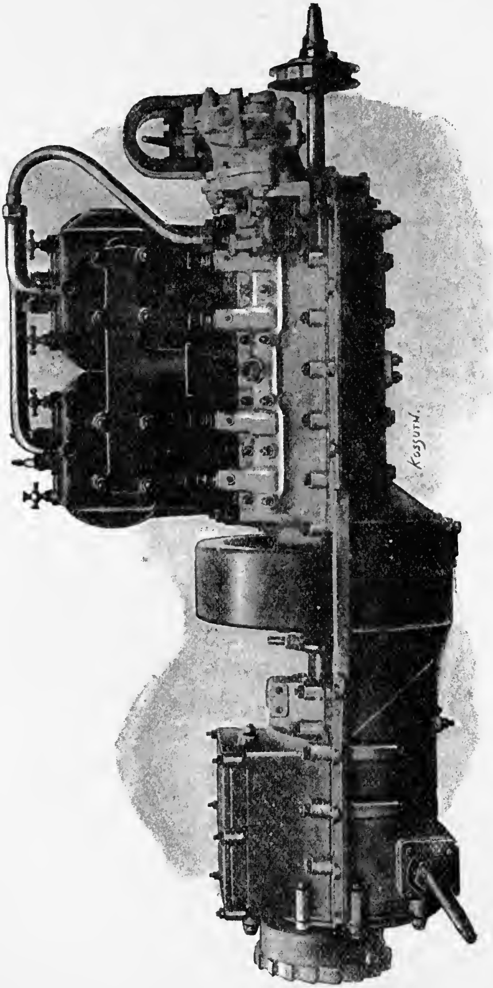


FIG. 21.—Modern Petrol Engine.

Wolseley. This type of engine has now been almost entirely discarded and replaced by an engine of a vertical type.

The Americans still adhere to the horizontal type of engines; to a limited extent these are built in pairs or fours, but English firms of repute do not now make horizontal engines. The early advocates chiefly consisted of the Wolseley Co., who constructed the horizontal type for a long time, and the Lanchester Co., who have been extremely successful with horizontal engines, but the manufacture of this type has been given up during the last few years.

Despite the fact that there are a number of two-cycle engines upon the market, which have proved eminently successful in practical working, the Otto cycle will continue to hold the field for many years to come.

The advantages obtained from the four-cycle engine amply counterbalance any disadvantages it may have, particularly for motor car purposes.

The Otto cycle is primarily a "non-pressure" system, that is, as far as the external portions of the engine are concerned, there are no external pumps, and no liability of the working fluid to leak out between the time of its production and its use in the cylinder.

There is, consequently, no wear and tear of the parts containing or conveying the working fluid, which in any pressure system might upset the proportions of the mixture and throw them out of their explosive range.

The action of the cycle is the same whether gas, oil, or petrol is the working fluid, and the process which is gone through is exactly the same as previously explained, with the exception that the whole series of operations must be performed in an infinitely shorter space of time.

Suction.—The advantage of the Otto cycle in this period is the regeneration which takes place during the suction and compression strokes, the heat in the cylinder assisting the vaporisation of the liquid fuel.

Now in a two-cycle engine this does not take place to the same extent, but against this, as far as the mixture is concerned, too great an addition of heat reduces the density of the mixture. Another disadvantage is that no scavenging takes place. The effect of the absence of a scavenging charge is that the whole of the compression volume, say 20 per cent. of the total volume of the cylinder, remains filled with the inert products of the previous explosion at the end of the exhaust stroke. These products, in addition to being of no value to the ensuing charge, heat up the mixture still further. It is possible in a two-cycle system to arrange an inflow of pure air which sweeps out the inert gas immediately before the new charge enters the cylinder, the advantage gained being an increase in the weight of explosive mixture per charge by some 20 per cent. per cycle. Owing to the rapidity of the suction stroke in a motor car engine, it becomes an important matter to fill the cylinder at the end of the stroke at nearly atmospheric pressure.

At the middle of the stroke when the increase of volume accelerates rapidly, the pressure may drop as much as 3 or 4 lbs. per sq. in. below the atmospheric pressure, but towards the end of the stroke the time element comes into play, and the velocity of inflow of the mixture overtakes the acceleration of the cylinder volume, thus causing the pressure to rise again. In the majority of high speed engines this time element is artificially increased by allowing the inlet valve to remain open until after the dead centre has been passed.

Although the velocity of the mixture through the inlet valve should not exceed 80 ft. per second, yet in some cases more than 400 ft. per second is attained. As the velocity of the incoming mixture varies throughout the stroke as explained, the maximum velocity greatly exceeds the mean.

The following table shows the reduction of pressure during the charging stroke, and the velocity of the mixture as a maximum and as a mean :—

Revolutions per minute	400	600	1,800
Mean velocity of charge, feet per second	58	170	458
Reduction of pressure, lbs. per square inch	0.031	0.25	1.62
Maximum velocity of charge, feet per second	91	267	719
Reduction of pressure, lbs. per square inch	0.07	0.62	4.0

The automatic inlet valve has practically disappeared, as, although it proved satisfactory for comparatively slow speeds, say up to 800 revolutions per minute in car engines, and even higher in bicycle engines, the inertia of the valve itself excludes it from use in modern high speed engines.

Compression.—The second stage, that of *compression*, has been the salvation of the internal combustion engine, as it is solely owing to the discovery of the economy to be obtained by compression that this engine is a commercial possibility to-day and has survived the experimental stage.

Compression has been taken advantage of in the steam engine for many years, its introduction being necessitated by the increasing speed of revolution in order to bring the reciprocating parts to rest gently at the end of each stroke. In the early gas engines no compression was employed, as will be seen in Chapter I., and the engines were exceedingly wasteful in fuel. The fact that the same amount of work can be done when the mixture is compressed with half the amount of gas to air ratio as when the mixture is fired without compression, is discussed in a previous chapter. It becomes evident that a loss of compression in a motor car engine enormously affects the horse-power that the engine will develop. In the earlier motor car engines when compression pressures were low, this loss, if small, was not so serious, but in modern high compression engines a small leakage becomes a serious factor.

The limits of compression with a petrol vapour and air mixture are lower than with a gas and air mixture, as the former will pre-ignite and suffer from spontaneous combustion at a lower temperature than the latter. Also in the majority of cases a motor car cylinder is run at a higher temperature than a gas engine cylinder.

The action of pre-ignition may not be apparent to the majority of motorists, particularly those who are accustomed to low compression engines, but it is indicated by an intermittent dull thump proceeding from the cylinder. The development of such a symptom should at once be investigated, as it may be caused by excessive carbonisation in the combustion chamber. The continuance of such a fault may lead to a failure of any part, as severe stresses are set up in the cylinder, which are communicated to the connecting rod and the crankshaft.

Ignition.—When ignition takes place in the ordinary way, a sudden stress is imparted to the cylinder, piston, crank, and connecting rod, and it is evident that the maximum permissible intensity of stress in these parts should be carefully considered in relation to the compression, and the magnitude of the compression pressure has a direct bearing upon the firing pressure.

The act of firing the charge or ignition is not, strictly speaking, a period in the cycle, as this takes place instantaneously, and a flame temperature is reached in the region of 1600 to 2000 degs. Cent. Such a temperature is not recorded by the indicator diagram, but it has an important bearing upon the question of lubrication. Nobody for one moment will pretend that a lubricant can exist in this high temperature in its liquid form, but the cylinder walls do not attain this temperature. If complete combustion has occurred during the propagation of the flame, expansion will take place along an approximately adiabatic curve, and no further heat will be added to the gases during the expansion stroke, except that regenerated from the cylinder walls.

The effect of the valve arrangement, however, is to modify this reasoning, and the position of the valves, whether in one or two pockets, or in the cylinder head itself, is marked in the working stroke and consequent running of the engine.

The adoption of side pockets is mainly one of accessibility to the valves themselves, and one of convenience in arranging the valve operating mechanism, but theoretically their adoption is not conducive to economy.

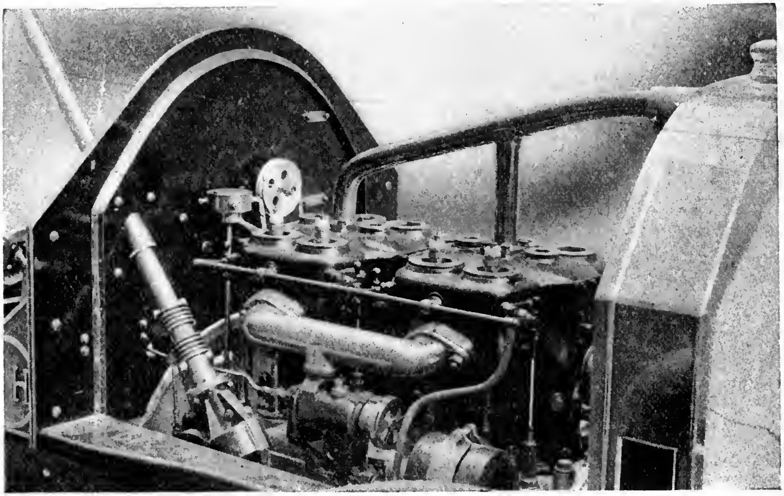


FIG. 22.—Petrol Engine showing Pockets.

Side pockets form receptacles for inert gas from the previous explosion, and are sources of excessive radiation to the water jacket. Any explosive mixture which is retained in the side pockets is out of the direct line of firing, often resulting in a form of sluggish combustion which is evident in an excessively hot exhaust, amounting to the presence of flame in the exhaust pipe. The ideal shape for the combustion space is spherical, thus giving the smallest ratio of wall area to volume, and the greater the departure that is made from this shape, the greater will be the thermal loss. If one pocket only is used, and the valves are facing one another, the incoming mixture impinges on the head of the hot exhaust valve with consequent ill effects.

Naturally the effect of pockets is not so great in the case of a long stroke engine as in a short stroke engine, as in the latter case a very flat shape of combustion space has to be made in order to produce a high compression.

Exhausting commences before the end of the working stroke has been reached, in order to allow the burnt gas to escape from the cylinder as rapidly as possible. The valve commences to lift at 85 to 90 per cent. of the working stroke, or expressed in degrees, say 30 degs., before the crankpin has reached its outward dead centre. It takes an appreciable period of time for the valve to lift from its seat as the action of a cam is not in a vertical, but in a sloping or inclined direction to allow the roller to traverse its face without placing undue stresses upon the guides of the tappet rod. For this reason the pressure in the cylinder does not immediately drop to atmospheric pressure when the valve commences to lift, but the effect of an early release is to reduce the thickness of the toe of the indicator diagram.

The mushroom valve has been universally adopted for the purpose of admission and release, but the Knight engine is a departure from this practice, and it may prove the sleeve to be a better means than the mushroom valve, as it certainly gives a greater area of opening without requiring any great operating effort.

Mushroom valves are fully open when their lift is a quarter their diameter, but owing to the enormous number of small blows to which they are subjected, their lift should be kept as small as possible. A corresponding increase in the diameter of the exhaust valve in order to obtain the requisite area of opening entails an increase of the opening effort in like proportion. The velocity of the gas through the valves must be kept within certain limits, and a speed of 80 ft. per second is the usual allowance.

Early failures of mushroom valves were in a large measure owing to their lift being too great, the shocks when returning to the valve seat causing the heads to break off short from the stems.

The careful design of valves and passages has recently received a large amount of consideration, and it is in a great measure owing to this fact that such high speeds of revolution have been attained by these specially constructed engines.

Restricted areas in valves and passages lead to very great loss of efficiency in addition to limiting the rate of revolution of any engine.

The results of numerous tests prove that an engine has a maximum efficient rate of revolution, and that above that rate the power falls off owing to the mean effective pressure decreasing more rapidly than the speed factor increases. As the horse-power of the engine is the product of these two quantities, there must be a critical maximum when this is the case.

Inertia.—Another limiting factor in the speed of an engine is the inertia of the moving parts and the effect of centrifugal force upon the connecting rod, which tends to buckle it.

For this reason very careful design is necessary combined with a minimum of weight. The forces at right angles to the stroke are most injurious in vertical engines, but whatever steps may be taken to balance reciprocating weights, their inertia has to be overcome by the engine.

Balancing of a high speed engine has been reduced to a fine art and is beyond the scope of this work.

Nowadays it is not uncommon to find engines with a speed of rotation of 1,800 to 2,000 revolutions per minute, whereas a few years ago 1,000 revolutions per minute was considered a very high speed for a moderate-sized engine. Also the modern tendency is to increase the length of the stroke. This has been brought about by the R.A.C. formula for the rating of engines which takes no account of the length of stroke or the speed of the engine. This formula is $\frac{D^2N}{2.5}$, where D is the diameter of cylinder in inches, and N is the number of cylinders. The formula holds good for engines of similar dimensions and is fairly approximate for piston speeds of 1,000 ft. per minute, but in some cases is very wide of the mark. The special Tourist Trophy cars of 1908 with four 4-in. diameter cylinders are rated as 25.6 H.P. by this formula, but the majority gave on test 60 H.P. and one over 100 H.P. This shows what can be accomplished by careful design.

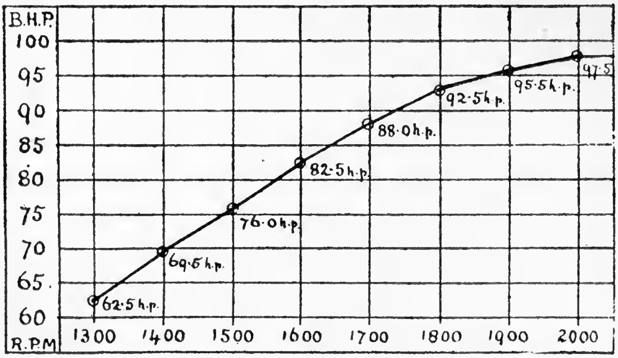


FIG. 23.—Curve of Horse-Power from 4-inch diameter Four Cylinder Engine.

"Four-Inch" Possibilities.—The results shown in the above diagram indicate the B.H.P. at different speeds which the Metallurgique Co. obtained on the test bench with one of the engines built by them for the "Four-Inch" race.

As will be seen, the horse-power rises from 62½ H.P. at 1,300 revolutions per minute, and attains a maximum of no less than 97½ H.P. at 2,000 revolutions per minute. On a subsequent occasion a reading of over 100 B.H.P. was reached at a speed of about 2,200 revolutions per minute.

There is some confusion between flexibility and controllability. Mr Dugald Clerk called attention to the fact that the former term is often applied when the latter is really meant. A flexible engine is one which gives the same, or approximately the same, power at various rates of revolution, and, as has been pointed out in an earlier chapter, this is impossible with the petrol engine as ordinarily made. Flexibility can only be attained by proportioning the mean effective pressure in the cylinder to the speed of the engine, as is possible in a steam engine where the boiler capacity is the ruling factor.

The Knight Engine.—Before leaving the subject of the modern motor car engine, it is impossible to omit reference to the Knight engine as modified in design and manufactured by the Daimler Co. This engine has appeared comet-like upon the motor world, and is well worthy of more than a passing reference.

The engine works on the Otto cycle in exactly the same manner as a mushroom valve engine, and there is, therefore, no foundation for the fifth claim in Mr Knight's paper read before the Royal Automobile Club. The only real difference is in the method by which the fuel is admitted to the cylinder and the exhaust passage is opened for the burnt mixture to escape. This is the ingenious part of the engine, and after a very careful inspection of the arrangement of the sliding sleeves, their velocities relatively to each other and to the piston itself, the author considers that the method has great practical value, and is not likely to suffer from undue wear and tear or heating, such as one would expect.

Many important features are only brought to light by a careful study of the engine. The first cursory glance might lead one to believe that the whole arrangement was unpractical and unmechanical. The cylinders inspected by the author were cast in pairs, the inlet and exhaust ports being large circumferential slots on opposite sides of the combustion chamber, each one extending about a third of the way round the circumference.

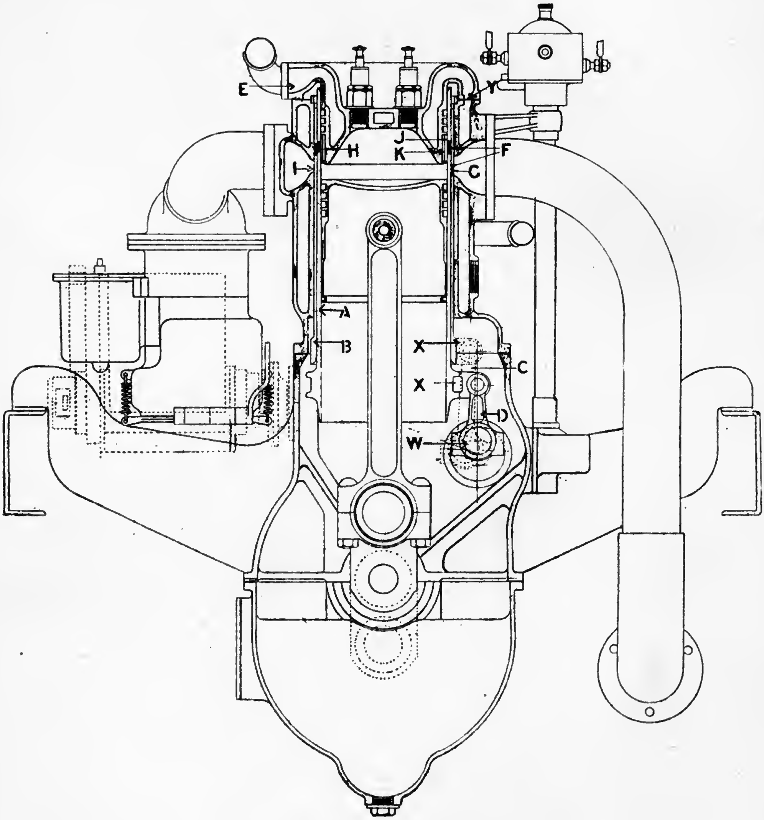


Fig. 24.—The Knight Engine.

The cylinder heads are separate castings bolted on to the walls but having the advantage of absence of pressure at the joint. The two sleeves, one inside the other, which act as valves, are extended upwards and make a ring joint with the cylinder head.

These sleeves have a vertical motion of 1 in., that being their total travel, but, as the operating eccentrics are set at a different angle to each other, they do not at all times move in the same direction. A quick cut-off is assured by this means. The inside sleeve weighs 10 lbs. and the outside sleeve 6 lbs.; these are not subjected to any pressure except that due to the angularity of the connecting rod, and the inventor states that the total pull required to move them is 76 lbs. in the upward direction and 60 lbs. in the downward.

The lateral pressure on the sleeves—this depending upon the coefficient of friction and consequently upon the lubrication of the surfaces—amounts in the 38 H.P. engine to a maximum of 900 lbs., and as the bearing area of the sleeves is 45 sq. in. this gives an intensity of pressure of 20 lbs. per sq. in.

Now, at the time of maximum lateral pressure, the sleeves are travelling in the direction of the piston, and this appears to be one of the most important features in the design. The piston thrust tends to drive the valves in the direction in which they are intended to go, instead of retarding their motion. At other times when the motions of the piston and sleeves are in opposite directions, there is virtually no lateral thrust upon them. The mechanical efficiency of this engine, as determined electrically, is 87 per cent., which is very satisfactory.

A number of claims made for this engine are only the carrying out of theories which have been expounded in the earlier chapters of this book, that risks of pre-ignition are reduced by machining the internal portions of the combustion chamber, and that certain advantages are obtained by the elimination of pockets in the cylinder head.

Referring to the diagram, the action of the sleeves is as follows:—At the commencement of the suction stroke the ports D and E come opposite to the opening of the slot into the cylinder; the exhaust and inlet ports are open at the same time for a few degrees of revolution of the crankshaft. The outer sleeve in descending cuts off the exhaust opening whilst rapidly increasing the inlet area to a maximum. The inner sleeve commences to rise, cutting off admission a few degrees after the outer dead centre is passed, and the two sleeves rise together during the compression stroke until the inner one is at the top of its stroke. Firing now occurs and the inner sleeve descends during the expansion stroke and the outer sleeve rises, the two ports becoming opposite and opening to exhaust at the usual time. The two sleeves descend together, giving full area to exhaust during the return stroke. Owing to the parts which are subjected to high temperatures being of uniform cylindrical dimensions, it is possible to make them of thin section of cast iron and thus to lighten the engine considerably. A higher compression being possible owing to the features of the combustion chamber alluded to, a greater firing pressure is experienced, necessitating heavier working parts, but in all, the engine is some 6 to 10 per cent. lighter than the earlier model of mushroom valve engine manufactured by the same company.

CHAPTER X.

POWER AND WEIGHT OF PETROL ENGINES.

DETAILS OF ARRANGEMENTS FOR OBTAINING HIGH SPEEDS.

THE student must be struck by the fact that the power of a petrol engine is so great in comparison to its weight, and particularly so when considered in conjunction with its prototype the gas engine. There are several reasons why the gas engine is so heavy; in the first place it was a rival to the steam engine and as such had to compare favourably with it as regards reliability and immunity from excessive wear and tear. This matter, in addition to its importance to the user, was and still is a consideration to the insurance companies.

In order to meet these requirements the various parts are made of massive dimensions, the piston speed is kept low, and the material used, although good of its class, is not of the expensive order such as is now obtainable.

The motor car engine, and still more so the aeroplane engine, must be kept within fine limits of weight per horse-power developed and the aim of designers is to produce the greatest power from a minimum weight of machinery. In addition to careful design and proportioning of material, the quality and nature of that material must be of the best for its particular purpose.

Cylinders.—Castings are constructed of the finest possible cast iron, which is in some cases as flexible as steel

The castings themselves are very thin, and after machining, the cylinder walls often do not exceed three millimetres in thickness. These cylinders, after boring, are lapped out to a dead smooth surface and in use become polished to a glass-like face. The water jackets are sometimes made of copper, either fitted on or electrically deposited, this practice being the reverse of gas engine practice, where the liner is the separate casting. Cylinders are usually made in one casting with the heads and valve pockets, and occasionally with the top half of the crank chamber, thus obviating all joints which are subjected to pressure and eliminating bolts or set-screws. The thickness of metal in the walls must be sufficient to stand the working pressure with a good factor of safety, and the metal must be so arranged that no great stresses are likely to be set up under expansion due to the high temperature of working. There is a tendency to revert to gas engine practice by making an expansion joint at the outer end of the liner, the jacket casting being bolted to an extension of the crank chamber. Cylinders are cast either singly, in pairs, or in sets of three or of four. The advantage of the block system is, that a lighter casting is possible with a greater water space in the jackets. A shorter engine is also possible with this arrangement, but it may be obtained at the expense of bearing area in the crankshaft main bearings. A large water space is not so likely to become choked up with lime or other deposit from the water, and the block unit reduces the number of pipes and water joints in the system. The objection to the block system is that, in the event of one cylinder being damaged by frost, or mechanical means, the whole unit has to be replaced, but with ordinary care, this eventuality need cause no alarm.

Engines which are likely to be subjected to severe frost should have separate jackets made of copper with provision for expansion; this precaution may often avert an accident.

Pistons.—Coming now to the reciprocating masses, the piston and its gudgeon pin have received considerable modification. Very light cast-iron pistons are now made, and although ample strength is provided for in the head, the walls are very thin and cored out round the sides where they act as guides. The front end of the piston usually has a lip cast all round which serves to pick up oil from the crank chamber and distribute it on to the cylinder walls. Light steel pistons are used in many cases and have proved quite satisfactory.

Gudgeon pins can be conveniently made in the form of a tube; this will give ample bearing area combined with lightness.

A good method of preventing the pin from rotating is to fix a small key at one end; the pin is driven in and a steel band prevents it from withdrawing or rubbing against the cylinder walls. This is better than employing set-screws, which are difficult of access and liable to break off.

Connecting rods are usually made of **H** section steel of a high quality such as vanadium, or nickel steel, this being particularly necessary to reduce weight. The bearings for both the large and small end are either made of gun-metal, or are casings lined with white metal. The large end bearing should be as light as possible consistent with strength, as this is all part of the moving mass. Great care must be taken to ensure the fixing of the two halves of the large end bearing so that there is no liability of the nuts slacking back. It is of great importance that when the connecting rod is fitted to the gudgeon pin, the large end bearing is exactly square with the sides of the piston; this can be tested when the connecting rod is fitted to the crankshaft. Any faulty fitting here is liable to cause an objectionable knock in running.

The large end bearing should, if possible, be so arranged that a liner can be fitted at any time between the brass and the connecting rod end, which for this purpose is conveniently made of the marine or **T** ended type. The object of the liner is to compensate for any wear that may take place and restore the piston to its correct distance from the crankpin, in other words to regulate the volume of the compression space.

Crankshafts should not be made too light, as rigidity is an important feature in addition to strength.

The greatest torsional stress comes on the shaft journal at the clutch end of the engine, and the web adjacent to this must withstand the whole torque of the engine together with the stresses which come upon it individually. The distance between the insides of any two neighbouring bearings is a factor of the ultimate breaking load of the shaft; it is therefore important that this should be as small as possible. Multi-cylinder engines, except in the small sizes, should have a bearing between each cylinder. Torsional stresses in a shaft are proportional to its length, and in a motor car engine the distance between the centre of the furthest cylinder and the flywheel is a ruling factor. Long shafts, which are necessary with

FIG. 25.—Crankshaft for Small Four-Cylinder Engine. This has only three main bearings.

long engines, should therefore be of ample dimensions to avoid whipping; a multiplicity of bearings will not stiffen a shaft which is too light. Crankshafts are made of various high-grade steels, and sometimes of mild steel, at the discretion of the designer, and in modern practice are drilled throughout the length, also up the webs and crankpins for purposes of lubrication, which will be referred to in a later chapter.

Valve operating mechanisms are driven from a gearwheel fitted to the end of the crankshaft. This wheel may either drive one camshaft if all the valves are on the same side of the engine, or two shafts if on opposite sides. Skew gearing is interposed when the valves are on the top of the cylinders and driven by an overhead shaft. A lengthy transmission is always liable to back lash or whipping of shafts, which will alter the period of valve opening if the mechanism is not of ample stiffness. Camshafts themselves are preferably made in one piece with the cams; this construction ensures their being correctly set at all times. When made of good material and properly case-hardened, practically no wear will take place on the faces of the cams. The gearing which drives the shafts, and the shafts themselves, should be properly encased, and it is good practice for the camshafts to be partially inside the crank chamber, where they can be well lubricated—an easily removable cover will enable the cams to be inspected or the shafts themselves removed at any time. The actual setting of the valves has been previously referred to, but the engaging wheels should be properly marked, so that the shaft, as a whole, can be removed at any time and replaced without risk of changing its position with relation to the crankshaft.

Power and Weight.—“ If the basis of measurement be two linear measurements, such as bore and stroke, the rating measurement may be the simple product of such measurements, or the product of their fractional powers.

"For engines of other than similar geometrical proportions, the same law applies, the values of the respective indices being chosen according to principles not so far investigated."

"The weight per horse-power of similarly designed engines varies inversely as the linear measurement.

"*Example.*—A four cylinder engine with 5 in. by 5 in. cylinders is (excluding flywheel) but of one half the weight of a proportionately designed single cylinder engine of the same power, *i.e.*, one of 10-in. diameter and stroke."

The following table indicates the relation between weight and carrying capacity of various vehicles, all of which, with the exception of the bicycle, are self-propelled :—

	Weight in lbs.	Passengers Carried.	Weight per Passenger.
Bicycle - - - -	30	1	30
Light motor bicycle -	85	1	85
Ordinary motor bicycle -	170	1	170
Tricar - - - -	250	2	125
Motor car - - -	1,680	4	420
Motor 'bus - - -	11,200	36	311
Suburban train - -	...	800 to 1,000	400
Electric train - - -	...	300 to 400	800

As far as the engine itself is concerned, and excluding radiators or accessories, we may assume that the power developed varies as the square of the linear dimensions, and therefore the ratio of power to weight varies inversely as the linear dimensions.

The horse-power of engines in relation to their bore, stroke, and weight was very ably discussed by Mr Lanchester at a meeting of the Institution of Automobile Engineers. He says that—"If two machines, say petrol motors, be built part for part alike, but differing in scale, their weights are as their respective linear dimensions cubed"; and also, assuming the same material is used in different machines for the same parts, "The power varies simply as the square of the linear dimension; such dimension may be the stroke or the cylinder diameter or other datum, provided the same similarly situated measurement be taken in each case."

If we assume that the power of an engine varies as $D(D-1)$, for similar engines the limit is reached at 2 in., but little is gained by making the diameter less than 3 in., which is about the unit in practice.

The following table is calculated out, utilising the formula—

$$\text{B.H.P.} = \frac{(2D+L)(D-1)}{6},$$

where D is the diameter of cylinder in inches, and
L is the length of the stroke in inches.

Assuming here L to be equal to the bore D, this simplifies the formula to

$$\text{B.H.P.} = \frac{D(D-1)}{2},$$

which gives results approximately the same as those obtained by the R.A.C. formula.

TABLE OF RATIOS OF WEIGHT TO POWER.

Bore in inches = D	2	3	4	5	6	8
Ratio of weight to power	8	9	10.7	12.5	14.4	18.3
$\text{B.H.P.} = \frac{D(D-1)}{2}$	1	3	6	10	15	28
$\text{B.H.P.} = \frac{D^2}{2.5}$	1.6	3.6	6.4	10	14.2	25.5

From this table an example may be taken of 3-in. and 4-in. cylinder power and weight. The power obtained from a 3-in. cylinder is, say, one-half that obtained from a 4-in. cylinder, and calculating out the weights of the two engines, two 3-in. cylinder engines will weigh $9 \times 3 \times 2 = 54$ lbs., and give a total of 6 H.P.

One 4-in. cylinder engine which gives the same power weighs $10.7 \times 6 = 64.2$ lbs., this shows the advantage to be in favour of the two smaller cylinders by some 20 per cent., as far as weight for power is concerned. From the opposite point of view, however, it is often convenient to have a fewer number of cylinders and to fit, say, four cylinders instead of six to give the same power even though the weight of the four may be greater.

Ignition mechanism should preferably be driven by direct connection to the crankshaft through a reduction gear, the teeth of which should mesh well and be free from backlash. Any slackness will cause erratic timing, and for this reason, generally speaking, a chain driven mechanism is not very satisfactory. A chain, too, is apt to become worn or to break; it is then somewhat difficult to replace correctly.

As the motor car engine is required to run at such a high speed the ignition must be very rapid, and the action of the mechanism, whether it be an induction coil, magneto, tappet, or any electrical or mechanical device, must be free from lag. The velocity of electricity is very high, equal to that of light, but that velocity is affected by the self-induction in the winding, the lag of the trembler, and the poorness of the contacts through which it has to pass. In order to compensate for this lag, means must be adopted for advancing the apparent time of the spark passing in the cylinder. Experiment has shown that the spark does not actually pass at the moment the external contacts are made—particularly is the lag noticed with induction coil arrangements, which have considerable lengths of wire for the current to traverse. As the whole working stroke of the piston only occupies something in the nature of a fortieth of a second, a lag of a tenth of this, or $\frac{1}{400}$ of a second, makes an appreciable difference in the power of the engine. A fixed ignition is sometimes spoken of; this is fitted to Brazier and other cars, but it must not be assumed that this is necessarily inefficient or sluggish at high speeds.

Electricity, generated mechanically by means of a dynamo—or magneto, which is the same thing—is dependent for its pressure or voltage upon the rate of speed at which the magnetic field is cut by the armature conductors. Consequently, as the engine speed increases, the armature generates current at a higher voltage, and this extra pressure accelerates the action of the system, or in other words, produces a spark of greater intensity at the plug.

CHAPTER XI.

FRICTION AND LUBRICATION OF ENGINES.

ANY two surfaces which are in contact and move relatively to one another, do so with a certain amount of frictional resistance. The magnitude of this resistance depends on the nature of the surfaces in contact, the velocity of motion, and the pressure between the surfaces.

Roughly speaking, with *dry* surfaces, the coefficient of friction, the ratio of the resistance to motion to the total pressure upon the sliding surfaces, is constant for variable loads; it decreases slightly as the load decreases; the frictional resistance also decreases somewhat with higher velocities.

It is often stated that the friction is independent of the areas in contact, but the friction is slightly less with small areas in contact than with large ones. Friction of rest is nearly twice as great as friction of motion.

Lubricated friction, however, is almost the reverse of dry friction, and much more nearly approaches the friction of fluids. A well lubricated surface has practically the same coefficient of friction at all loads, so that it is the aim of the engineer to keep a thin film of oil always between two sliding surfaces. If this is accomplished the actual metals should never touch, but in order to retain oil in this way two chief points must be considered: (*a*) the intensity of pressure or load per unit area upon the surfaces, (*b*) the viscosity of the lubricant.

The time element has also some bearing upon the subject, as when surfaces are intermittently loaded, such as crankpins, the lubricant has not sufficient time to squeeze out, the load only being applied for a fraction of a second at a time. The pressure on a crankpin is the product of the firing pressure in the cylinder and the area of the piston, but this is about double the mean pressure which acts upon the crankpin. The coefficient of friction between the pin and its bearing, when properly lubricated, may be taken as 0.036.

The development of the high speed engine has been accomplished to some considerable extent by the improvements in lubricants and the methods of applying them. When dealing with crankshafts it was stated that these are often drilled, and in modern practice oil is forced through the crankshaft to the main bearings and also through the webs of the shaft to the crankpin. In many cases a pipe is taken up the side of the connecting rod to convey oil to the gudgeon pin. The crank chamber is made in the form of a reservoir, and an oil force pump is fitted at one end; this is either driven from the camshaft or is a portion and an extension of one of the valve lifters. Strained oil is forced through the shaft, thus ensuring a proper lubrication of the bearings. In certain engines, the crankpins are lubricated by means of scoops which are fixed to the crank webs. Oil is injected from a pump in the form of a stream impinging upon the rotating scoops. Centrifugal force drives the oil up drilled passages to the crankpins.

The earlier method of drip feed acts very well. The oil in this case is pumped from a tank into a distributor or manifold pipe, sight feed tubes leading from thence to the crank chamber where the oil dropped on to the bearing caps. Air pressure can also be used in place of a positive pump, but the pump is self-regulating, running only when the engine is at work and at a speed proportional to it. Exhaust pressure is inadvisable as the pipe leading from the exhaust is liable to become fouled and the presence of exhaust gas upon the surface of the oil is not to be desired. Lubricating oil loses its nature when exposed to flame; it is therefore necessary to replenish oil which has been previously used for piston lubrication from time to time.

The quality of the oil itself, and its suitability for the particular purpose it is employed for, has a great influence upon the wear and tear which takes place in the engine and also upon the efficiency of working. Oil should retain its lubricating properties at high temperatures particularly when it is required for cylinder lubrication, and should therefore be tested for viscosity at higher as well as at ordinary temperatures. Uniformity of manufacture is very important, as, when a satisfactory oil has been found for any particular purpose, reliance must be placed upon the maker of that oil to keep its quality up to the mark or difficulties may arise from time to time. Mr Alex. Duckham has supplied the author with the following table of his tests showing the variations which occur in various oils. The most important figures are the viscosity at high temperatures and the difference between that at high and that at low temperatures, and the open flash point.

TABLE SHOWING PROPERTIES OF LUBRICATING OILS.

Maker.	Colour.	Sp. Gr.	Viscosity.		Open Flash Point. ° Fahr.	Composition.
			At 70° Fahr.	At 140° Fahr.		
A. No. 1	Red, filtered	.890/5	2,000	325	483	Compound
No. 2	,,	.900/5	1,200	230	415	,,
No. 3	,,	.900	...	255	455	Pure mineral
No. 4	,,	.907	...	157	426	,,
B. No. 1	Deep red	.885	725	103	392	,,
No. 2	Green black	.882	...	123	...	,,
No. 3	Red filtered	.900	...	...	...	,,
C.	,,	.894	...	445	540	,,
D. No. 1	Deep red	.907	1,200	137	420	,,
No. 2	Filtered red	.905	2,045	240	463	,,
No. 3	Dark red filtered	.904	3,098	253	478	,,

TABLE SHOWING PROPERTIES OF LUBRICATING OILS.

(MR J. VEITCH WILSON.)

Oils.	Specific Gravity at 60° Fahr.	Viscosity at 70° Fahr.		Viscosity at 212° Fahr.		Viscosity at 350° Fahr.	
		Actual.	Per Cent.	Actual.	Per Cent.	Actual.	Per Cent.
Sperm - - -	.878	323	100	88	27.2	68	21.1
Gas engine - - -	.907	845	100	89	10.5	68	8.1
Heavy gas engine -	.905	2,430	100	110	4.5	74	3.0
Motor oil (water-cooled)	.891	5,003	100	178	3.6	88	1.8
,, (medium) -	.894	6,655	100	181	2.7	94	1.4
,, (air-cooled) -	.893	9,200	100	220	2.4	96	1.0

In this Table the viscosity of each oil at 70° Fahr. is taken as unity.

Sperm oil, which is an oil of low viscosity, retained at 350 degs. Fahr. 21 per cent. of its original viscosity, this being a very high percentage. A gas engine oil gave 8 per cent. and a heavy gas engine oil 3 per cent. at the same temperature, whereas ordinary motor oils came down to 1.8, 1.4, and 1.0.

CHAPTER XII.

CLUTCHES AND CHANGE SPEED GEARS.

Clutches are a necessary evil with a petrol driven car, although a good clutch is the salvation of all the mechanism between it and the road wheels. The day will undoubtedly come when clutches can be dispensed with, but as long as the present form of gear change is in vogue, so long must a clutch be interposed between the engine and the change speed gear. Clutches may be broadly classed into three types—the leather-faced cone clutch, the internal expanding clutch, and the multiple disc clutch. The former type has stood the test of time, and is still as popular as ever, as when the angle of the cone is properly designed it leaves little to be desired. When carefully used the leather lasts for many years; the mechanism is easy of adjustment and is simple in nature. A cone clutch can be slipped when convenient or desirable, and can, when necessity arises, be rapidly engaged. The internal expanding clutch, as used on the old Mercedes cars, was fitted with two metal shoes, which did not embrace the whole of the internal surface of engagement; the frictional area in this type is not so great as in the cone type of clutch, and generally such a clutch cannot be slipped conveniently. The inner surface also is apt to pick up foreign matter, and to oxidise when standing for any time.

Plate clutches and multiple disc clutches have made very rapid advancement during recent years, particularly the Hele-Shaw clutch. This consists of circular plates having a **V** shaped corrugation around the periphery. The corrugation increases the amount of the surface of each plate and the gripping effect threefold, and allows the diameter of the plates to be kept smaller in consequence.

All the plates in Hele-Shaw clutches have driving notches either on their outer on inner circumference. The outer plates, which are made of high-grade phosphor bronze, are driven by the engine, and the inner plates of mild steel drive the clutch shaft, and so transmit the power to the gear box. The clutch case marked A in the sectional drawing is bolted to the flywheel, and so revolves with the engine. Around the inner side of this case there are

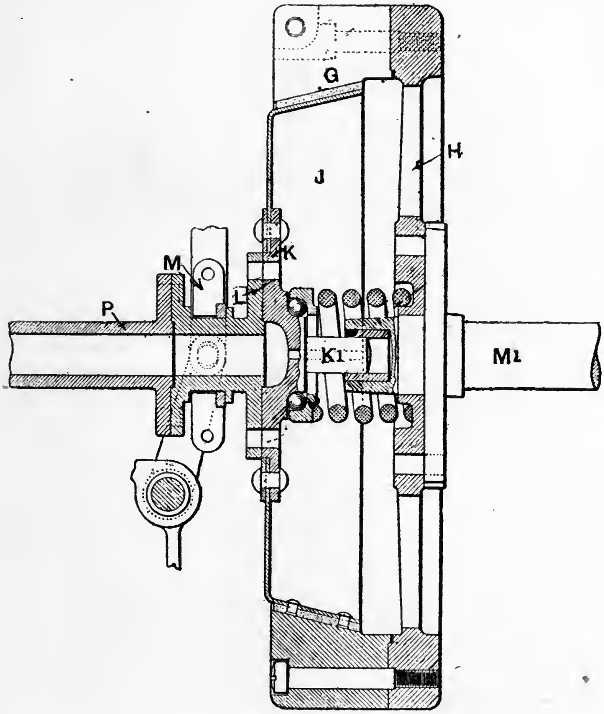
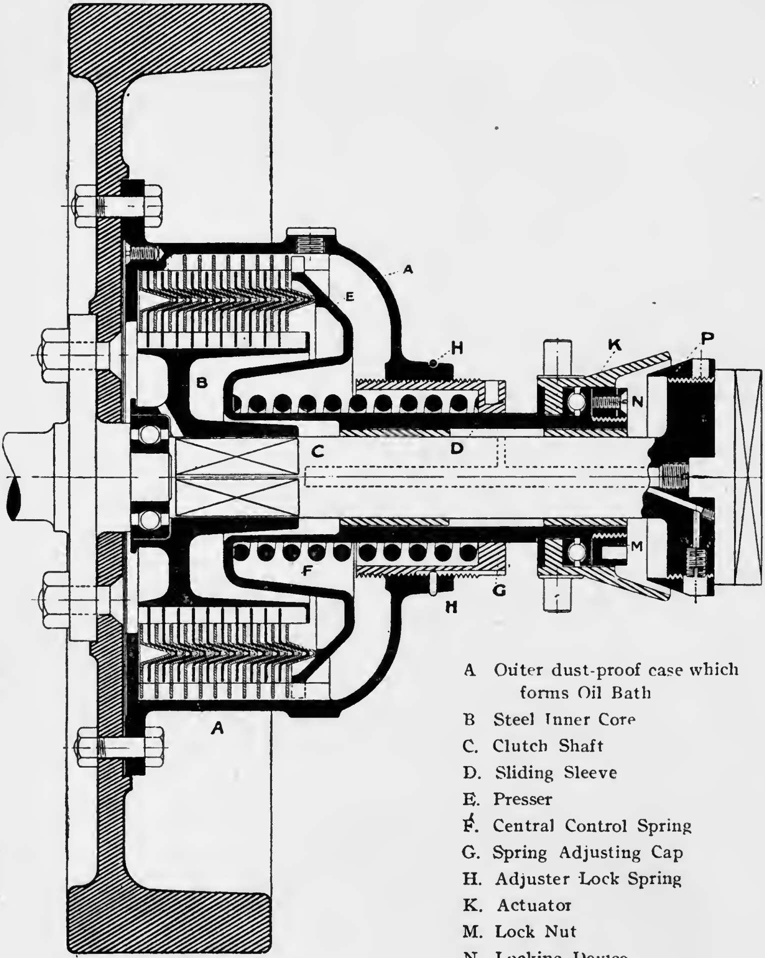


Fig. 26.—Leather-faced Cone Clutch.



A Outer dust-proof case which forms Oil Bath
B Steel Inner Core
C. Clutch Shaft
D. Sliding Sleeve
E. Presser
F. Central Control Spring
G. Spring Adjusting Cap
H. Adjuster Lock Spring
K. Actuator
M. Lock Nut
N. Locking Device
P. Coned Clutch Brake

SECTIONAL VIEW OF PERFECTED 'HELE-SHAW' CLUTCH BOLTED IN POSITION ON FLY-WHEEL

FIG. 27.—Hele-Shaw Clutch.

teeth or feathers which engage with the notches in the outer (phosphor bronze) plates, so that these outer plates always revolve with the engine. Supported on a ball bearing on the end of the crankshaft is a steel core shown at B, which is connected with the clutch shaft C. This core, like the case, has driving teeth, but on the outer side, and these engage with the inner (steel) plates. There is a sleeve D sliding on the shaft and ending in a disc E, which presses the inner and outer plates together. This presser, as it is called, is normally kept tight against the plates by the pressure of the main clutch spring F, the other end of which is held by the spring adjusting cap G screwed into the boss on the end of the case. In this way it is arranged that no thrust is exerted on the engine or the gear box while the clutch is engaged. The spring adjuster is locked in position by the wire spring H, which can be raised out of engagement while the spring pressure is altered by screwing up the adjuster.

While the full spring pressure is keeping the outer and inner plates pressed together, the power of the engine will be transmitted to the gear shaft.

To disengage the clutch, the presser is moved back by means of the actuator K, so as to take the pressure off the plates. This has two pins engaging with the pedal levers, whereby the motion of the foot pedal is transmitted to the presser through the ball bearing and the lock nut M. This latter is prevented from slacking back by a simple locking device.

When the pressure has been taken off the plates, these might tend to stick together on account of the oil. To prevent this, the outer plates are fitted with small flat springs, which are in compression when the clutch is engaged. When the presser slides back, the small springs throw the outer plates apart, and make the clutch quite free. Occasional breakages of these springs having occurred after prolonged use, a new type of laminated spring is now being fitted. This is quicker in action and as durable as the plates themselves.

As the correct action of the clutch depends upon the behaviour of a film of oil, it is of vital importance that oil of the requisite viscosity and nature be used for lubricating the discs.

This type of clutch cannot be suddenly applied, as the oil takes an appreciable time to flow out, and allow the plates to come into contact with one another.

Change speed gears may appear at first sight to be an unnecessary and expensive adjunct to the mechanism of a motor car, but from the reasoning in Chapter VI. on the testing of engines, it will be seen that the power of an engine depends on the number of firing strokes which take place in unit time. The slower the rate of revolution, therefore, the less will be the power, other conditions remaining the same. When a car is in use on the road there are two occasions when the linear element is small, or the distance through which the pressure in the cylinder acts in unit time is small. These occasions are (1) when the car is throttled down in traffic and very little power is required to propel it; (2) when ascending a hill, and although the throttle is full open, the speed of the car and of the engine likewise falls.

Now, the slower the speed of the engine the less is the power developed; this occurs in hill climbing at the exact moment that maximum power is required.

Some mechanical method must, therefore, be resorted to, whereby the engine speed will be such that it is developing maximum power when the resistance of the road is greater than can be overcome by the engine at a slower rate of revolution.

As an instance of this road resistance, or rather resistance of the acceleration of gravity when hill climbing, supposing that a car is moving at the rate of 10 miles per hour on a good road and that the horse-power required to propel it is, say, 5,

A gradient of 1 in 45 will require 10 H.P.
" " " 1 in 22 " " 15 "
" " " 1 in 16 " " 20 "

This power must be developed at the road wheels in order to maintain a velocity of 10 miles per hour.

If the engine is large enough to develop 20 H.P. at the road wheels at a speed of 10 miles an hour, no intermediate gearing would be necessary, but on the level such an engine would only be working at one quarter of its maximum power when running at this slow speed. It is quite possible to dispense with a change speed gear altogether if a large enough engine is employed; the large engine would, however, in such a case, work at a very low load factor under ordinary conditions.

In the above instance assume that the engine will only develop 5 H.P. at the road wheels at 10 miles per hour, and that a gradient of 1 in 16 is met with; by reducing the speed of the car to one quarter and keeping the speed of the engine the same, the full 5 H.P. will be developed, but the car will take four times as long to cover the distance assuming cent. per cent. efficiency of the reduction gear.

Fig. 28 shows some interesting curves which bring out the relations between engine speed and horse-power, and the relative speed of the car to rate of engine revolution when different gears are in operation.

The diagrams are the result of a test on a 14 H.P. Siddeley engine made by the Wolseley Co., which had four cylinders 90 mm. diameter × 102 mm. stroke. The horizontal scale shows engine revolutions per minute, the vertical scale the miles per hour of car speed as referred to the curves of gears, and brake horse-power as referred to that curve. It will be seen that the range of speed on the direct drive was from about 5 miles per hour, equal to 220 revolutions per minute, up to 42 miles per hour at 1,700 revolutions per minute. At the lower limit of speed the engine developed practically no power but just continued to turn, keeping the car moving on the level.

It will be seen that the engine is developing its maximum power at speeds from 30 to 40 miles per hour, that

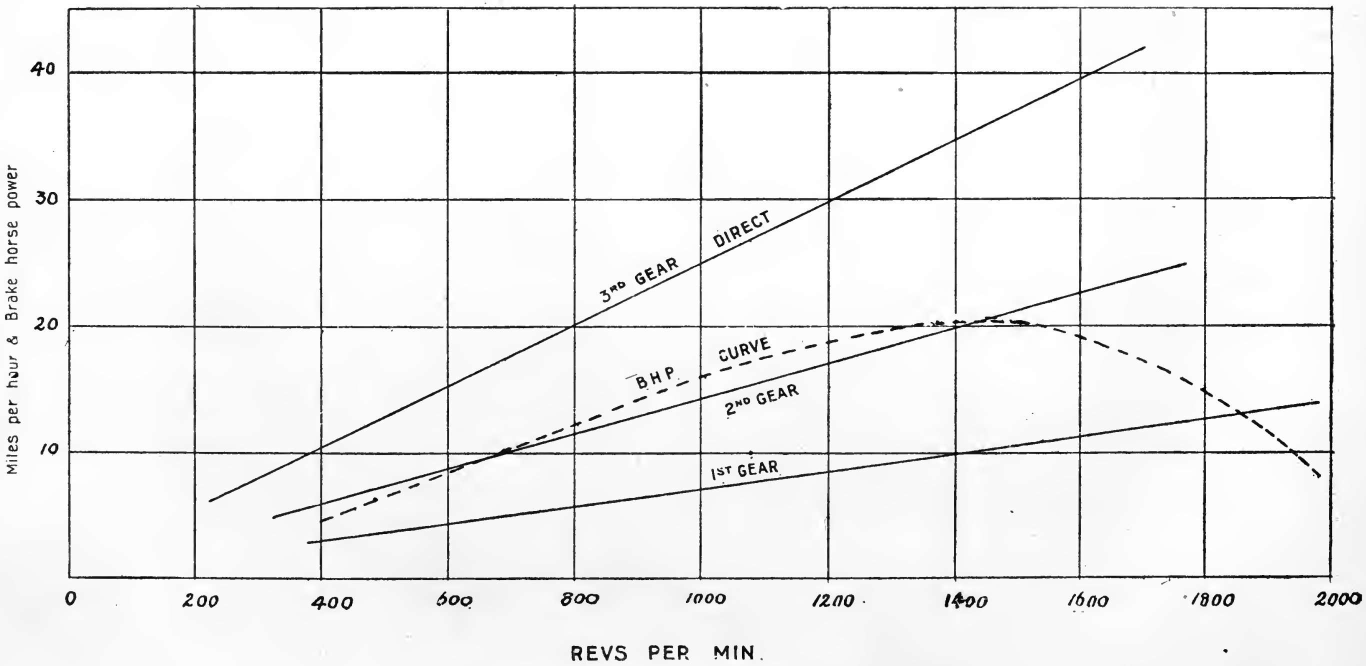


FIG. 28.—Relation between Engine Speed and Horse-Power.

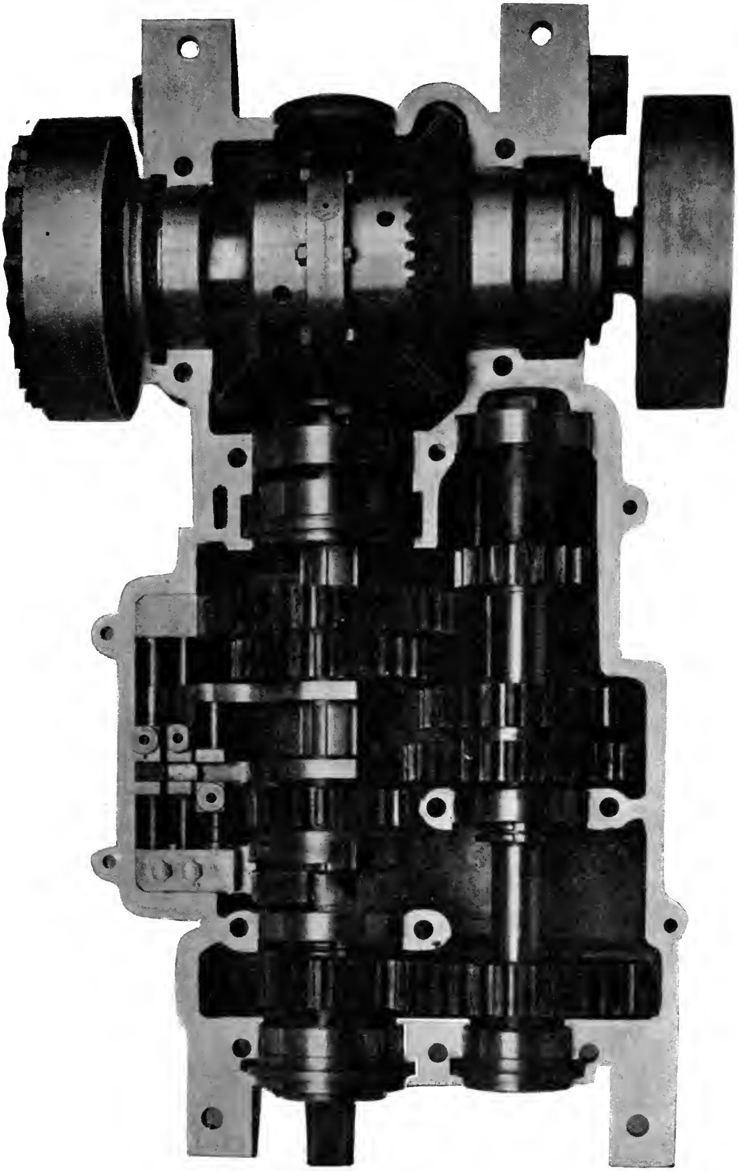


FIG. 29.—Arrangement of Change Speed Gear.

power being 19 to 20 B.H.P., but at higher speeds the falling off in power is clearly shown, until at 2,000 revolutions per minute it has dropped to 8 B.H.P. At a speed of 15 miles per hour, say when climbing a hill, if the top gear remains in engagement the engine develops only 8 B.H.P., but if the second gear is engaged 16.5 B.H.P. is developed by the engine—more than twice the amount. Now, if the speed drops to 10 miles per hour on this gear the power of the engine has fallen to 10 B.H.P., but on changing down to the first gear the power of the engine due to its increased rate of revolution rises to 20 B.H.P. If the car is running on the level at the above speeds, it would not be necessary or advisable to change down the gear, as the power required to propel the car is amply provided when the engine runs slowly, as will be seen from the previous table of horse-power required on gradients.

At the moment of starting from rest a greater effort is necessary than that required to maintain the speed on the level as explained under the heading of "Friction and Lubrication," and at this moment one half of the clutch is revolving at the speed of the engine whilst the mechanism connected to the other half is at rest. The interposition of a speed reduction gear will therefore greatly reduce the difference of the relative velocities of the two portions of the clutch when first brought into engagement, and will allow the car to pick up speed without unduly retarding the speed of the engine.

The type of change speed gear, which is almost universal, is that which was originally employed when belt driving was discarded, and is known as the Panhard sliding gear. This arrangement is an adaptation of the ordinary gear used on a lathe where trains of wheels on two parallel shafts are brought into gear, the primary shaft driving the secondary shaft at a reduced speed, the secondary shaft pinion driving back on to a spur wheel which runs on the same centre line as the primary shaft, but at a lower speed. Owing to the fact that more than one ratio of reduction is required in a motor car change speed gear, a train of wheels slides on a keyway or square on the primary shaft,

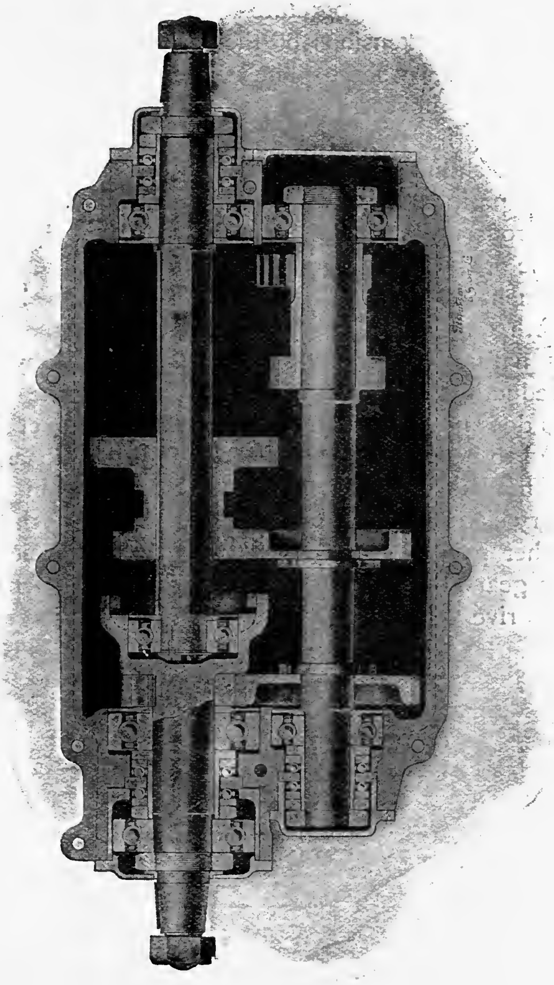


FIG. 30.—Gear Box fitted with Hoffmann Ball Bearings.

any wheel of which can be slid into gear with its mating wheel on the secondary shaft. These wheels operate the return drive. A very usual practice is to allow one drive to be direct along the primary shaft, and in this case the sliding train is put out of gear with the secondary shaft, which revolves idly. A dog clutch is then engaged; this is often formed by extensions of the sliding train and the pinion on the primary shaft. Thus the sliding train and the shaft on which it moves, revolves at the same speed as the pinion on the primary shaft and consequently that of the engine. This sliding into mesh of gears which are running at different peripheral velocities one to the other seems to be a barbarous practice, but a little skill in manipulation enables the operator to so accelerate or retard the engine at the moment of engagement, that the relative velocities of the teeth on the two wheels are practically the same. There is naturally a loss of mechanical efficiency in a double reduction gear of this nature, but on the direct drive this does not occur. For this reason a direct drive is arranged to be in use under all ordinary conditions.

Some makers only fit a single reduction gear in which the primary shaft at all times drives the secondary through one or other pair of gear wheels—this is more efficient on the lower gears, but does not have the high efficiency of the direct drive.

CHAPTER XIII.

TRANSMISSION GEAR.

LIVE AXLES AND CHAIN DRIVE—BRAKES—THE DIFFERENTIAL GEAR.

" **Live Axles.***—According to the popular idea, the term 'live axle,' when applied to a car, signifies that the drive between the engine and road wheels is transmitted by shafts and not in any way by chains. We cannot definitely state that either chain transmission or shaft transmission was the prior method adopted in motor car work, as, from the early days, it appears that both were employed in some form or another. In the case of a notable pioneer car, the engine drove direct through its change speed gears on to the back axle; in that case, of course, the engine was situated close to the axle itself, as was the practice of the period. There was also the belt arrangement in the early Benz, but as this style of drive has practically disappeared, we will give it no further consideration.

" During what we might consider the transition period of motor car construction, opinions differed widely as to the advisability of fitting a live axle drive upon a motor car, and the early advocates of this type of drive had to endure many hard criticisms at the hands of the chain drive supporters. These same chain advocates began to realise that the live axle had points when the Napier car so fitted won the Gordon Bennett Cup in 1902. Since that date the live axle has undergone very little change in the main

---

* By permission of *The Car Illustrated.*

principle, and the majority of makers who now adopt this type of drive are making an axle practically identical with those made in 1902-3 in France.

"As an engineering device there is very little new in the main idea of a right-angled direct drive of this nature, but, owing to the mechanical weakness of a divided shaft, methods of supporting the shaft and counteracting any tendencies for weakness have received attention from designers. The resultant appears to be an adoption of the sleeve encasement whereby the whole of the right-angled shafting is rigidly supported in a right-angled casing, this casing resists all external shocks and carries the weight of the car. In some designs also the casing itself, unaided by torsion rods or radial stays, is so designed that the thrust upon the *chassis* is transmitted through it from the road wheels, and also the resistance to a contra rotary motion in the opposite direction to that of the road wheels.

"It will be seen that there are many and varied stresses to be borne by a live axle, particularly when it is unassisted by external members, and for that reason, when high powers have to be transmitted, essential stiffeners must be correctly designed and fitted for certain specific purposes. First consider torque rods, such as are fitted in the Renault car. Directly power is applied to the road wheels, as when the clutch is let in, two equal and opposite stresses are set up. There is a circumferential stress along the two tyres which causes the wheels to fly round, when they fail to grip the road, which we may designate P, acting at a radius R, being the radius of the wheel itself, measured from the centre to the tread of the tyre. Therefore P by R is the moment of this force, considering the pair of wheels. This rotary movement must be counteracted, otherwise the axle itself would revolve in the opposite direction. The axle must therefore be supported in order to prevent this, and the moment of the supporting force must be equal to P by R.

"In the Renault and similar cars there is a long arm, or a pair of arms, fitted, converging at a point forward of the axle and rigidly connected to the axle itself, preferably to the enlarged portion of the casing around the crown wheel, the length of this arm being R^1 and preferably longer than R. We must then have for equilibrium a resisting force P^1 at the end of R^1 when the power is applied. This resisting force is obtained by utilising the weight of the car itself, and transmitting the pressure thereto through the medium of a link fitted with buffer springs, or in some cases simply a rigid bolt.

"When no supplementary torque rod is fitted the sleeve encasing the cardan shaft is utilised for the purpose, the resultant pressure P^1 being transmitted to the *chassis* through the single universal joint at the rear of the gear box. It will thus be obvious that only one universal joint between the gear box and the axle becomes possible.

"Considering now the thrust of the road wheels, which propels the car upon the road, we again have two equal and opposite direct forces. There is the tractive force, which exists whether the car be chain driven or of the live axle type, the limit of which occurs when the weight upon the wheels is insufficient to maintain a fixed contact between the wheels and the road. This force must be transmitted to the mass of the car in the same way that the thrust of a ship's propeller must be transmitted to the hull of the ship. There are several methods of effecting this, and perhaps the most familiar is by means of radius rods.

"Radius rods are the two limbs of the parallelogram which are necessary to produce a parallel motion, and to keep the axle itself in its proper position relative to the *chassis*. They must therefore be of an exact length, equal to the length from the centre of the axle to the centre of the universal joint at the rear of the gear box. When such is the case, whatever the vertical motion of the axle may be—due to irregularities of the road surface—no excessive wear will take place at the universal joints.

Fig. 31.—Live Axle with Encased Shafts.

"It may be noticed that in some cars the forward end of the rear springs is fixed, one end only being suspended from a shackle. Generally this practice is adopted in order to dispense with radius rods, and the thrust is transmitted through the top spring blades. Unless this arrangement is very accurately designed a good deal of sliding motion is bound to result in the square transmission joints, as the axle will be swinging from a different radius to that of the cardan shaft.

"The springs must be fixed at their seats to the casing enclosing the back axle, whereas in the correctly designed torsion rod type, the spring seats float upon the sleeves.

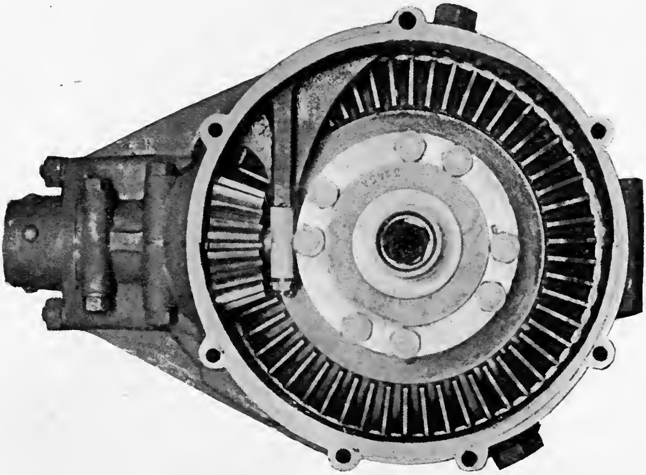


FIG. 32.—Bevel Pinion and Crown Wheel.

"Finally, there is the system of making the cardan shaft sleeve its own radius rod, and transmitting the thrust of the car through it to a thrust bearing in the gear box similar to that used on board ship. This system appears to work well in practice when sufficiently lubricated. Now in a system of this kind thrust collars and ball rings must be fitted to transmit the thrust from the axle casing to the cardan shaft, and these can be combined in the ordinary thrust bearings fitted behind the bevel pinion and at the outer end of the cardan sleeve.

"Concerning the bevel drive, which exists in most cars, it is very essential that the pinion and crown wheel run on their true pitch line, so in addition to the ordinary bearings fitted to support the shafts, ball-thrust collars, preferably adjustable, are fitted. It will be evident that when two wheels of this nature transmit power at right angles, there is a great tendency for the wheels to fly out of mesh altogether. In common phraseology we may say that the function of the ball-thrust collars is to 'keep the bevel wheels up to their work.' The disadvantage of the live axle drive has been that these bevel wheels and the differential gear have been inaccessible as compared with many chain driven cars, where these wheels are in the box with the change speed gears and easy of access.

"If anything does go wrong with a live axle, the breakdown is usually serious, but as long as everything is in proper working order, and in its correct adjustment, there is no doubt that for small or medium powered cars the live axle is the most satisfactory and efficient. For in a chain driven car of the ordinary type we have the right-angled drive, but with the addition of two side chains with their attendant friction, wear, and noise. As regards heavy cars, the chief objection to a live axle is the weight of the moving parts unsupported by springs. There is no doubt that a heavy axle, with its differential and other toothed wheels continually bumping through road vibration, wears out tyres, and in itself must depreciate owing to excessive vibration, whereas when the rear wheels are chain driven, the weight, unsupported by springs, is considerably reduced."

Chain Drive.—The alternative to a live axle is a chain drive, which may consist of either one central chain driving on to a differential casing on the back axle, or two side chains each driving one of the rear wheels direct.

Fig. 33.—Radius Rod combined with Brake Drum for Chain-driven Car.

In the latter case the differential gear, crown wheel, and bevel pinion are placed in the gear box. The chain drive has the following advantages—the bevel wheels are easy of access and can be inspected without much trouble; the removal of one cover in a fairly accessible position enables one readily to see if wear is taking place. The differential gear is also placed here so that the foregoing remarks apply equally to it. With a chain drive it becomes a simple matter to alter the gear ratio, this being done by changing the chain sprockets on the countershaft and adjusting the length of the side chains to suit. As the road wheels in the case of a chain drive are supported at each end of a solid axle which carries no gear wheels or other weighty material, the unsprung weight is less with a chain drive than with a live axle. It is the unsprung weight in a car which causes wear and tear to the unsprung mechanism in addition to the extra wear on the tyres. The rear dead axle must be kept its correct distance from the cross driving shaft, and for this purpose radius rods and distance rods are used; these latter are in compression, as they must counteract the tension in the driving chains (see Fig. 33).

It is of great importance that distance rods be properly adjusted, so that the axle itself is maintained in a position at right angles to the centre line of the *chassis*—otherwise the chains will not engage properly with the teeth on the wheels and at high speeds may become liable to jump off the wheels altogether. There is also a considerable amount of wear and tear taking place in driving chains at all times, particularly when these are exposed to alternate mud and dust on the road and water in the garage. Therefore, driving chains require much attention in the matter of lubrication and frequent cleaning with paraffin followed by an immersion in hot black lead and tallow.

A chain driven car is invariably more noisy than a live axle car owing to the action of the chains themselves. If one chain happens to break, it cripples the action of the countershaft brake on the car, for the braking action as well as the driving effort has to be transmitted through the chains.

Brakes are the most important accessory to a car, as if the car cannot be stopped, the lives of the passengers are endangered as well as those of other road users. It is most important, therefore, that efficient brakes are fitted—the law insists upon two independent sets.

The usual practice in motor car construction is to fit a countershaft brake operated by a pedal and a pair of brakes in the drums of the rear wheels operated by a hand lever.

In the author's opinion the reverse should be the custom, as he finds the road wheel brakes to be the correct ones for ordinary usage, and it is sometimes inconvenient to spare a hand for the side brake lever. The reason for this opinion is that the rear wheel brakes are applied direct, and the action does not stress the differential gear, thereby putting pressure on the backs of the teeth; nor in the case of a chain drive does the braking of the rear wheels affect the tension in the chain by suddenly reversing all the stresses. The average car driver does not conceive the magnitude of the severe stresses of braking, which are often far greater than any driving stresses. Supposing a car can be accelerated from rest to a speed of 20 miles per hour in 50 yds., and the same car is brought to rest from a speed of 20 miles per hour in 25 yds., the stresses due to braking are twice the stresses due to driving effort. Early cars suffered greatly from the lack of sufficient braking power, but in modern cars this feature has been more carefully considered, so that at the present time little is to be desired. Water cooled brakes are not uncommon in large powered cars, and even in medium sizes radiating fins are cast or forged on to the brake bands.

The design of brakes generally adopted, consists of a contracting band operating on a drum and acting through the propeller shaft, supplemented by internally expanding shoes inside drums on the rear wheels, as shown in the diagram. These shoes are generally supported at one point, and their free ends expanded by means of a cam or suitable levers. In order to apply equal braking force to the two wheels, careful adjustment of the brakes must be made, but compensating mechanism is often fitted to obviate any risks in this respect. The main brake rod actuates a floating crosshead at the fulcrum, from the ends of which the two separate rods, one to each wheel brake, are taken to the braking mechanism; this ensures equal tension upon the two brakes, and reduces the risk of skidding when the roads are greasy. Metal to metal brakes are preferable to fibre-lined shoes, which are apt to burn; a gun-metal lining to the brake shoes runs well on a steel

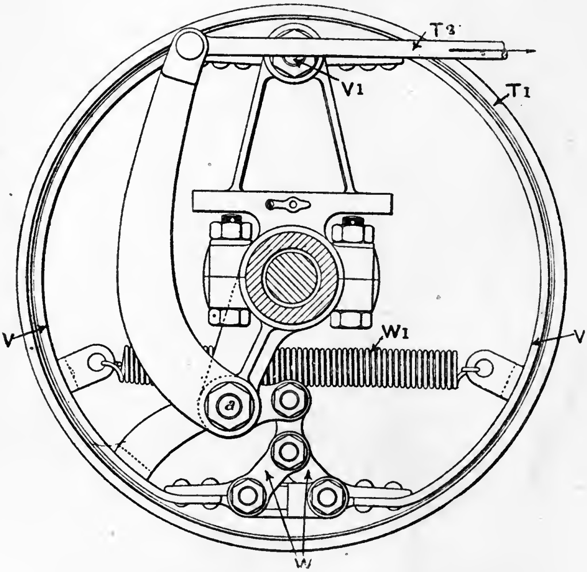


FIG. 34.—Expanding Type of Rear Wheel Brake.

as it is driven by teeth on the opposite end of the diameter of each individual planet pinion.

These pinions and sun wheels are sometimes made parallel instead of bevel, but the action is the same in either case.

CHAPTER XIV.

FRAMES—SUSPENSION.

FRAMES are usually beyond the notice of the average public, although the correct suspension of a frame has an important bearing upon the behaviour of the car—particularly so when a heavy body is fitted. In the case of a motor car, the object of the designer is primarily to transport the car and its passengers in comfort with minimum wear and tear to both. The passengers need a body for their comfort and convenience and the mechanism a frame for its adequate support. It becomes a question whether the same frame can suffice for both.

The modern car frame amply fulfils these requirements, but the early frames gave cause for much complaint from the coachbuilders who had to design bodies to fit them, and even from the motor car makers themselves. In the horse-drawn vehicle the wheels have simply to be trailed along, but in the motor car they have to propel the vehicle. As regards the springing, too, a horse-drawn vehicle is so arranged that its wheels can lag slightly when surmounting an obstacle on the road; when the obstacle is passed over, they return to their normal position relatively to the vehicle. In the case of a motor car this is not so, as no lag can be allowed and only a vertical motion is possible, thus increasing the difficulties of suspension. In the early days the provision of a separate frame for the machinery rigidly attached to the rear axle was tried, but found to be undesirable, and it is by a process of evolution that it has been considered preferable to support the body and the machinery upon the same frame, which is mounted above both axles and upon independent springs. It is necessary, therefore, that the frame should have ample stiffness to support the two, otherwise the transmission mechanism is liable to become strained, resulting in broken shafts, or undue wear upon the bearings. Any distortion of the frame is also liable to cause trouble with the carriage work and to open joints in the woodwork or crack the varnish. The majority of makers to-day employ pressed nickel or chrome steel channel members which are deeper at the centre, tapering at the two ends, and at the forward end are generally swept inwards to allow greater lock for the steering mechanism.

These frames are reasonably strong, providing greatest depth where the greatest bending moment occurs, and are cross stiffened by similar channel members to prevent racking. Tubular frames, at one time popular, have now almost disappeared, they were a modification of bicycle construction. Triangulation as an adjunct to stiffness is taken advantage of in some cars by riveting members at the rear of the frame across the two corners, and this is a particular advantage when a transverse rear spring is fitted. Some cars are fitted with a narrow frame throughout their length in order to obviate any sweeping in of the side members at the front, whilst others are fitted with a secondary frame narrower than the main frame to which the engine and gear box are bolted. Probably the best type of frame or *chassis* from the point of view of rigidity is the Decauville blind *chassis* (see Fig. 36), which consists of channel steel side members, to the lower flanges of which a sheet steel apron is riveted. This gives absolute rigidity to the frame in the vicinity of the engine and gear box, and owing to the base plate of these two parts being made in one casting (see Fig. 21), and bolted to this apron, it is impossible for the two to become out of alignment.

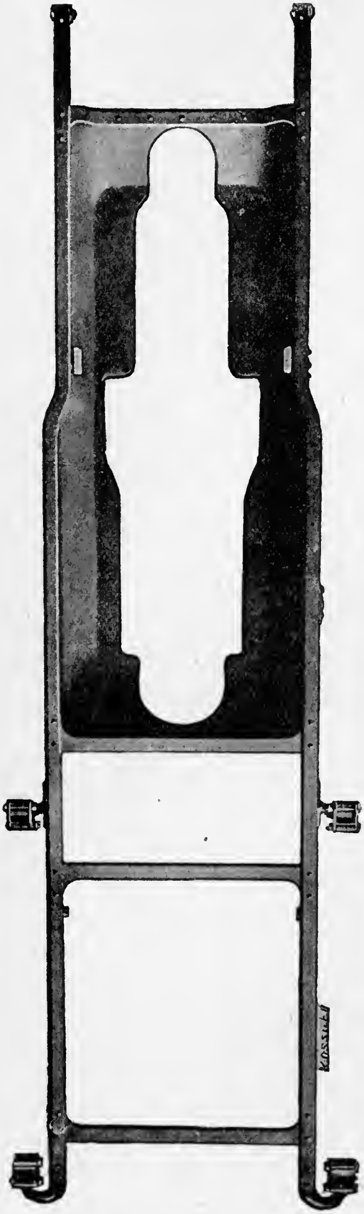


FIG. 36.—Blind *Chassis.*

This method of construction, though dating back to about 1902, has been adopted by many of the leading makers in their latest models.

This blind *chassis* also prevents any mud or stones thrown up from the road from disabling the mechanism of the engine, and tends to a general cleanliness.

In the Napier car, tie rods are fitted diagonally across the frame in the form of triangulation before referred to. These rods are in tension and thus resist any tendency to buckling of the frame. It is becoming a common practice in live axle cars to sweep the side members of the frame upwards where they pass over the rear live axle. This allows a low floor level to be kept whilst maintaining ample clearance for the action of the springs, particularly where three-quarter elliptical springs are employed. In many frames a transverse front member is dispensed with, reliance being placed upon the fixing of the engine to afford the necessary rigidity, but when a car is driven round a corner, or on one side of a cambered road, side stresses are set up which are conveyed by the near side spring to the *chassis*. These stresses set up a twisting action in the dumb irons, and the near side dumb iron can conveniently be relieved of a portion of these stresses by fitting a rigid cross member at the front of the frame.

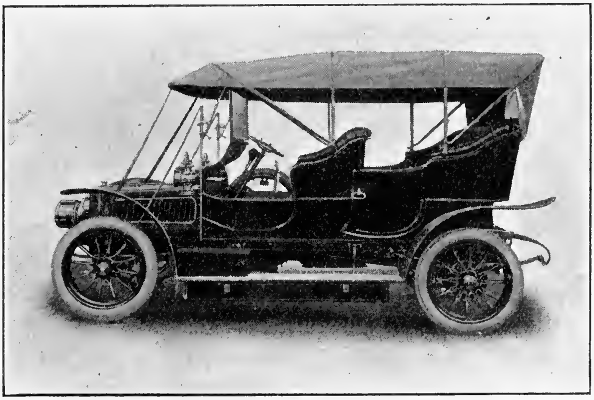


FIG. 37.—Showing Arrangement of Three-quarter Elliptical Rear Spring.

Suspension.—The earlier method of suspending a *chassis* upon four semi-elliptical springs is still adhered to by many makers to-day. Modifications in this form of suspension are found by (1) the addition of a transverse rear spring to the ends of which the rear ends of the back axle springs are fitted—this method tends to produce side roll; (2) in place of the rear dumb irons, a quarter elliptical spring is fitted at each side, making in all three-quarter elliptical springing; (3) totally elliptical springs or some modification of this and cee springing; (4) the

Lanchester form of suspension which has two single-ended springs projecting at each end and riding upon the two axles.

The transverse rear spring is going out of favour, and in many cases is being supplanted by three-quarter elliptical springing, but the transverse spring tends to equalise the load on the two rear side springs and keep them about the same level. It also requires no rear dumb irons or side projections beyond the rear of the *chassis*. As about half of the weight which is carried upon the back axle has to be borne by the transverse spring, it must be securely fixed to the *chassis* at its centre, and there are several ways in which this may be carried out.

It is a common practice to extend the frame by a bracket in order to afford this support, and this may originally have been an adaptation to suit stock frames. There is generally enough room for this bracket without its causing an unsightly appearance, unless carriage bodies are very long. This bracket must be very rigid as well as strong, and be fixed securely and braced to the main members of the *chassis*; in some cases the bracket consists of extensions of the triangulation work at the rear of the frame itself. When quarter-elliptical springs are used they may be either shackled to the side springs or pinned to them direct, depending, of course, on whether the axle itself swings from a fixed centre such as a radius rod.

Good engineering practice allows the axle to swing from one fixed centre only; this being the case, springs should not be directly connected to the *chassis* at all, unless, as is the custom with some makers, the spring blades act as radius and torque rods.

With regard to front springing, the semi-elliptical spring is still universal, but as ordinarily constructed it has the disadvantage of affecting the steering when one spring is more deflected than another. Also, if both the springs deflect, when hinged at the front end and shackled at the rear end, the axle moves bodily towards the steering pillar, thus tending to throw the wheels out of their course. The deflection of one spring tends to throw the axle out of right angles to the centre line of the *chassis.*

The suspending pairs of shackles, in the case of the rear springs, are frequently made out of one piece, but two separate plates are often more convenient for the front springs, when they are fastened direct to the frame without the use of a supporting bracket. The shackles on the rear springs are usually in tension, and those on the front springs in

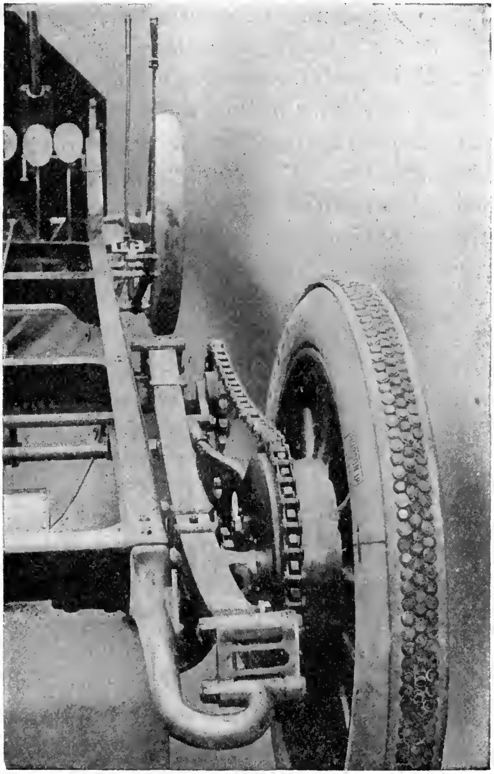


FIG. 38.—Solid Rear Shackles in Tension.

compression. The proper lubrication of shackle pins is most important, and often one of the most neglected duties.

The intensity of stress here is very great, and the shackles themselves are continuously working on the pins. This results in the lubricant being squeezed out from between the rubbing surfaces, and accumulating upon the side of the pin upon which there is no load. Here it picks up any dust, which in turn finds its way into the joints.

Only when squeaking occurs does the lack of lubrication become known, and continual personal attention will alone remedy this evil. The pins and shackles generally suffer considerably from wear, which may become dangerous owing to the pins thinning down.

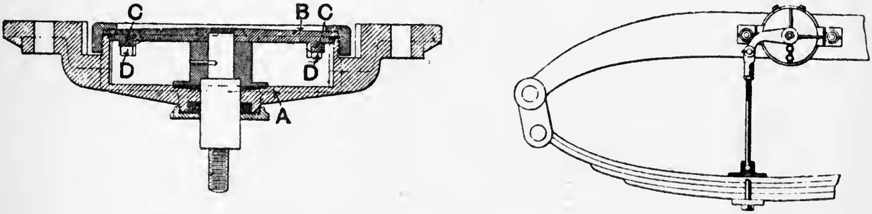


Fig. 39.—Shock Absorber in Section and Fitted.

Shock absorbers are frequently fitted especially to fast cars, and their effect is quite noticeable upon the ease of running of the car. These are usually some form of frictional device which tends to bring the oscillations of the spring to rest quickly. After surmounting an obstacle the tendency is for the oscillations to continue for several periods afterwards, and a further obstacle or unevenness of the road surface may cause a very considerable increase in this oscillation if its phase coincides with that of the previous oscillation.

On an undulating road surface the amplitude of these accumulated effects may be such, that, should it synchronise with the natural period of the suspension of the car, serious damage to the springs may result. Mr Lanchester has given much time to this question of suspension, and he says that the only way to avoid this synchronisation is to provide suitable dampers or shock absorbers. One of these is shown in diagram (Fig. 39) which clearly explains its action. The duty of a shock absorber is to bring the *chassis* back to its normal position without shock and with a minimum number of oscillations. There should only be a return of the first movement to a position slightly below the normal. It is claimed for the Glissoire absorber, Fig. 39, that this object is attained by using oil which fills the casing A. This casing contains a rocker carrying two displacing vanes, there being a diaphragm fixed in the main casing A between them. The oil aperture between the two halves of the chamber is of variable size, and is regulated by the vertical motion of the axle. In many of these devices the friction between the leaves of a coiled spring is taken advantage of; there is, however, no theoretically perfect shock absorber which only acts in the direction required, but a correctly designed spring may be made self damping to a certain extent.

When a laminated spring is deflected, its constituent plates slide over one another and considerable friction results. This is usually the friction of dry surfaces, as lubricant is seldom retained between the leaves of such a spring for any length of time. When these leaves are pressing hard on one another, the friction will be greater than when the pressure is deficient or absent. Springs are therefore made so that there is considerable initial pressure between the leaves before the weight of the car comes upon them. This is arranged by making the leaves of the same radius, so that when fitted together the outside of one does not fit closely to the inside of its neighbour.

When the leaves are bolted together considerable force must be used to make them lie closely and bear firmly upon one another. In this way initial friction and consequent damping is set up.

By designing the shorter leaves thinner than the longer ones, and making the radius of curvature of the shorter less than that of the longer leaves, the damping effect can be improved. This variation in the thickness of the plates proportions the stress equally upon them all, as if the shorter ones were made of equal thickness to the longer ones, they would be stressed more heavily and would be the first to fail. The function of any system of suspension is to allow the road wheels to follow the contour of the road surface without imparting a rising and falling motion to the *chassis*.

A very important and little considered feature of suspension is what Mr Lanchester terms "side location." "If the tyres of the vehicle were smooth so as to offer no resistance to lateral sliding on the road surface, the centre of gravity of the vehicle, instead of being thrown sideways at each change of lateral gradient, will not undergo any lateral displacement whatever, for a lateral displacement involves a lateral applied force, and if the tyres are frictionless no such force can exist; hence when the vehicle is passing over changes of lateral inclination, the road wheels will wriggle sideways as they travel along the road. Thus lateral motion imparted to the car produces a lateral reaction on the tyres. The magnitude of this reaction varies with the amplitude of the lateral motion and is proportional to the height of the centre of gravity above the ground."

With an ordinary form of shackled spring a practically definite side location of about half an inch is provided by the slackness of the shackles, but in any case the height of the side location, that is the distance of the fixing of the *chassis* from the ground, should be as small as possible, for other things being equal the amplitude of the side wobble will be in proportion to this distance.

In the Lanchester suspension this distance is very small as the cantilever springs sweep well downwards, and in the present type of car this distance is from 12 to 13 inches. In the ordinary type of suspension this distance is 24 inches.

CHAPTER XV.

STEERING—RADIATION.

Steering mechanism is almost universally controlled by a wheel, but it was not always so. In the earliest forms of the motor car, tiller steering was the usual practice. The tiller of M. Levassor was similar to that in a Bath chair and was moved in the opposite direction to that in which it was intended the car to go. This was an unstable mechanism as the momentum of the driver's body always tended to accentuate any deviation from the straight course. The early tiller steering simply consisted of an arm fixed to the lower end of the steering column operating the Ackermann gear or stub arms through a rod. This is obviously a reversible gear, as should the wheels encounter an obstacle upon the road, the lateral pressure tending to turn the wheels out of their course is transmitted through the lever mechanism to the tiller itself. As distinct from this type, irreversible steering gear is always fitted to motor cars and is met with in two forms, one the worm and sector type, the other the worm and nut.

In either case the lower end of the steering column terminates in a worm which in the sector type is engaged with a sector pivoted at its fulcrum, having a projecting arm which moves to and fro as the sector is partially rotated about its fulcrum when the worm is turned round.

The weakness in this system is the comparatively small area of contact between the worm and the teeth in the sector, as only two teeth at the most are engaged at the same time. The vibrations of the road wheels set up a good deal of wear and tear upon the faces of the centre teeth, which are practically the only ones in use.

The worm and nut arrangement is somewhat similar, except that the worm is embraced throughout the whole of its circumference by a nut, which can be adjusted to fit the worm more closely when worn. The nut is prevented from rotating and moves up and down as the steering wheel is turned. The diagram (Fig. 40) shows the arrangement, and it will be noticed that the movement of the nut causes a small shaft with suitable arms to rock. The movement of the lower arm actuates the wheels through a rod.

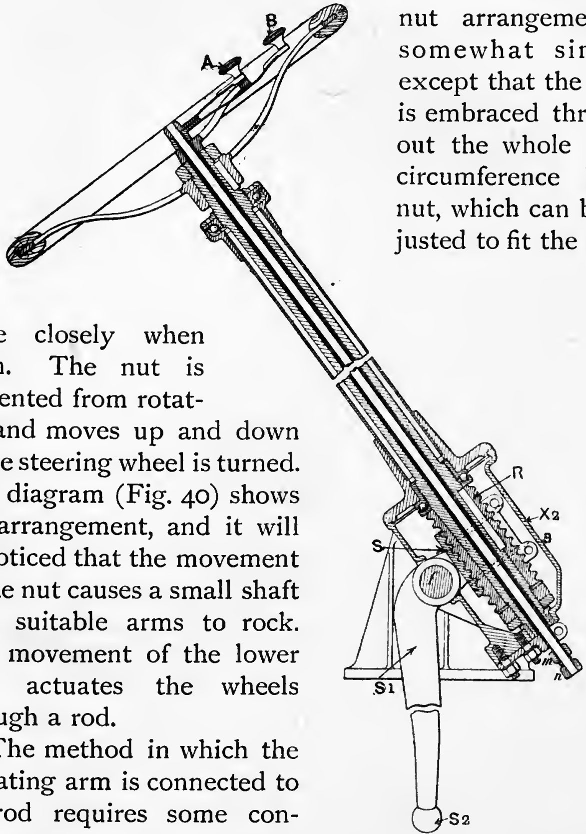


FIG. 40.—Steering Gear, Worm and Nut Type, also Method of Control Actuation.

The method in which the actuating arm is connected to its rod requires some consideration, as many accidents have occurred owing to these two becoming disconnected. The more common practice is to terminate the arm in a ball which fits into a socket in the rod. The socket is of the nature of a tube, having a slit or opening sufficiently wide to accommodate the waist of the arm above the ball. A hard steel cup is slipped into the tube, the latter being screwed to the end of the rod. The tube is then pushed over the ball, which is held up by the fit of the slit round the waist of the rod. A second hard steel cup is then put in from the end of the tube, and a plug or adjusting nut is screwed home until the two cups just give the ball freedom to move in all positions without much back lash. The weak point of this arrangement is that the weight of the rod is supported by the slit in the tube, and if this opens out or becomes worn, or the ball on the end of the arm wears flat on its sides through vibration and dirt, they are apt to come adrift. In some cases the arm terminates in a fork or a pin at right angles, which is a more reliable means of taking the weight of the rod. This joint should always receive careful attention.

Parallelism of the two front wheels is often overlooked until undue wear takes place upon the front tyres, or the steering is found to be awkward. Each front wheel is supported by a journal which runs on ball bearings; the journal pin usually terminates in a large fork, each eye of which is supported by the axle ends. A large vertical pin is fitted through these fork ends and through a long boss

FIG. 41.—Front Axle with Stub Arms.

in the end of the axle. In some cases the fork is on the axle, but this does not affect the argument. These forks have stub arms forged with them, one on the near side, and two on the off or driving side; these are usually at right angles. The arms being in a line parallel with the centre line, are connected together by a bar which should be of such a length that the wheels are parallel with each other. The transverse arm on the off side is connected to the steering rod, generally by means of a knuckle joint. The arrangement of the two stub arms which are connected together, and their rod, must be such that when the front wheels are turned to take a curve, the amount of turning is different in each case. Both wheels must turn to the same radial length; this means that the inside wheel must move more than the outside wheel.

When the connecting rod between the two stub arms is placed behind the front axle, it must, therefore, be shorter in length from centre to centre than the distance between the two pins about which the wheels swing. If the arm is in front of the axle, the reverse must be the case.

The amount by which this rod must be shorter or longer depends upon the length of the arms; the exact design is somewhat complicated. The stub arms must be set nearer together or farther apart to retain the parallelism of the wheels to allow for this difference in length.

Radiation or dissipation of the heat taken up by the water in the cylinder jackets is a process which has been very much accelerated, thus permitting a much smaller weight of water to be carried for the purpose than heretofore, whilst the weight of the tank has been eliminated and that of the radiator itself considerably reduced. The function of a radiator is to transmit the thermal units stored up in the water into the surrounding air, and for this purpose two essential features are necessary—maximum radiating surface of the containing vessel with maximum conductivity of the material of which the vessel is composed.

There is in addition the importance of allowing a sufficient body of air to come in contact with the radiating surface in unit time in order that the requisite amount of heat can be carried away by the air. Radiating surfaces are made of gilled tube, bent into any convenient shape, or of a nest of thin short tubes packed closely into a frame having their outside ends soldered together. In the former case the water is contained inside the tubes, in the latter the spaces between neighbouring tubes constitute the water space; air is drawn through the tubes themselves. A flat tube has the maximum radiating surface in relation to the amount of water which it can contain, and a most efficient system consists of a series of flat tubes separated by zigzag metal strip.

The author has conducted a number of tests on a radiator constructed of this flat tube and corrugated ribbon. The frame was 33 in. square and six elements of two rows of tubes each were taken in the first trials. The air thus had to pass twelve rows of tubes and corrugated ribbon. Situated behind the radiator was a fan 30 in. diameter driven by an electric motor. The tests were made in a warmed room. Temperature of air inlet, 80 degs. Fahr.; temperature of air outlet, 180 degs. Fahr.; total rise, 100 degs. Fahr.

B.T.U. extracted from radiator per hour = 590,400, and per minute = 9,840.

The power required for fan and motor = 1.47 H.P.

The radiator was then divided and three elements tested with the following results:—

Temperature of air inlet -	65 degs. Fahr.	80 degs. Fahr.
„ of air outlet -	115 „	125 „
Total rise of temperature -	50 „	45 „
B.T.U. radiated per hour -	560,000	468,000
„ per minute -	9,160	7,810
Horse-power for motor and fan	1.53	1.40

These figures show that the three-element radiator had only about 20 per cent. less radiating capacity than the six-element, and that very little was gained after the temperature of the outflowing air had reached 125 degs. Fahr. The mean temperature of the radiator itself was 212 degs. Fahr. in all the tests.

From the tests it is evident that there is small advantage in having a deep radiator, *i.e.*, with a great distance from front to back; also experiment shows that the bulk of the radiation takes place in the upper part of the tubes. These two facts should influence the design of radiators.

The tubes in the radiators on trial were about $\frac{3}{8}$ in. wide and the water space was $\frac{1}{16}$ in. wide; the narrow edge projected to the front. This apparatus was specially made by the Albany Manufacturing Co. Ltd. of Willesden.

CHAPTER XVI.

IGNITION MECHANISM.

THE ignition of the explosive mixture in the motor car cylinders is now always effected by means of an electric spark. Not so many years ago, engines fitted with tube ignition were still met on the road, the system being a survival of the gas engine tube system, with the exception that platinum tubes were used. Electricity may be provided from three different sources in the modern car :—

1. Primary dry batteries, which may be from two to twelve in number.

2. Secondary batteries or accumulators, which require charging from time to time from an external source of electricity.

3. Dynamos or magneto machines, which generate electrical energy by means of their mechanical operation.

The applications of sources (1) and (2) are somewhat identical, as the primary current at a pressure of about four volts is conducted round the primary winding of an induction coil, its passage being interrupted at certain intervals by a contact breaker worked from the half-time shaft of the engine. One revolution of the contact breaker is usually allowed to two revolutions of the crankshaft.

The effect of this interruption is to cause fluctuations in the magnetic effect of the primary winding on the soft iron core upon which it is wound, thus setting up and destroying the magnetic field in the vicinity of the coil. A secondary winding, consisting of a large number of turns of fine wire, is wound upon the primary winding, but quite independently of it, one end is earthed to the frame of the car—the other end being conducted to one of the sparking plugs, or through a distributor to all the plugs in turn.

The effect of the disturbance of the magnetic field is to induce a current in the secondary winding whose pressure is greater in proportion to the number of turns in the winding, and the rapidity of magnetisation and demagnetisation.

In order to assist this latter action an electrical condenser is connected up across the poles of the primary; this does not actually allow current to pass through it, but stores up a certain quantity of electricity in static form. The static charge is expended or discharged through the primary circuit every time the contact maker or trembler breaks circuit, and as this takes place in the opposite direction to the magnetising current, demagnetisation is assisted. This action also reduces the sparking at the various points of contact in the circuit. It is important that the condenser should be of sufficient size, otherwise the action will be sluggish.

The primary winding of the coil may or may not have a trembler in circuit. If there is no trembler a rapid make and break at the contact will induce a single discharge, or one spark at the plug from the secondary winding. The presence of a trembler produces a continuous shower of sparks which goes on as long as the trembler vibrates. This vibration makes and breaks the circuit rapidly whilst the contact is made by the contact maker on the engine shaft. The adjustment of this trembler blade is very important, as its action is extremely rapid, and the running of the engine depends to a great extent upon the rapidity of make and break, and consequently the intensity of the spark produced in the cylinder. If one coil is utilised for supplying a number of cylinders great care must be taken in its selection, as such a coil should be specially wound to carry the increased load. Its condenser should be of ample capacity, and the platinum contact points on the trembler blade and its contact screw of suitable proportions, as these burn away much more readily than in the multiple coil system. A useful accessory is shown in Fig. 42 of the plug switch which enables any plug to be short circuited, so that the action of one or more cylinders and the ignition in the same may be readily tested without removing any wire. In trying an engine it is useful to test each cylinder separately by switching off all except the one in question. This action repeated for each cylinder in turn should give the same rate of revolution in every case if the ignition is working well.

The contact blocks may be either of the make and break type, or the sliding or roller type. The make and break has a series of projecting screws equal in number to the number of cylinders; these are insulated from the body of the block, and from each one a wire is taken either directly or through a sliding contact to the primary winding of one of the coils. Opposite each screw a blade is fixed at one end only; a platinum contact is riveted into this blade opposite to that on the screw adjacent to it.

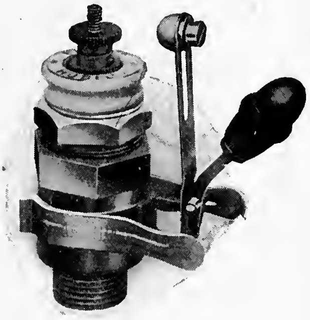


Fig. 42.—Sparking Plug fitted with Testing Switch.

The free end of each blade carries a roller which is pushed outwards by a revolving cam once per revolution.

The blade contact, which is normally a small distance away from the screw contact, is thus pressed against it, completing the circuit.

The roller system consists of a fibre ring, into the inside circumference of which metal contact blocks are fitted. The driving spindle projects through a base plate to which this ring is fitted and has attached to it a small crank arm carrying a roller at one end. This roller is pressed into contact with the inner circumference of the ring by the tension of a small spring on the crank arm.

As the spindle revolves, the roller travels along the inside of the ring, and as it passes each contact block in turn it completes the circuit to the coil connected to that block. The revolving portion in each case is earthed, thus the positive current passes to the blocks or screws, and through the revolving contact to earth, *i.e.*, the frame of the car, and thence through a wire to the negative terminal of the battery.

The magneto is the usual form of ignition to be found in the majority of cars. Sometimes it is the only system and at others it is supplemented by a coil and accumulator system working on to separate plugs. Some magnetos are of the low-tension variety, such as the Castle, which supplies current to the usual trembler coil and high-tension distributor. The low-tension magneto pure and simple was the first of its kind in the field, and is still relied upon by many motor car manufacturers.

In order to obtain a spark in the engine cylinder, the igniter, which is screwed into the cylinder head, consists of a fixed and moving contact. The fixed contact is usually in the form of a pin, being a projection of the igniter body. The moving contact is a small cranked lever, the fulcrum spindle passing through an insulating bush which maintains a gas-tight joint. A special set of operating mechanism must be worked from the camshaft so that each lever can, in turn, be flicked out of contact by means of an external trigger operated by a push rod. Normally contact is made, a spring holding the cranked lever against the pin in the cylinder. At the moment of firing contact is broken by means of the trigger, and a spark passes. The objection to the low-tension system is the possibility of leakage of gas around the spindle of the moving contact, and also the extra complication of actuating mechanism with its consequent need of adjustment.

In the *high-tension magneto* this gear is not required, as a current of sufficiently high pressure is generated either by the machine itself or by its induction coil, causing a spark to pass between two points of an ordinary plug. Such a plug is shown in Fig. 43, and is so arranged that the centre or insulated contact is quite near to the earthed contact when cold. As the plug heats up in running, this centre contact expands in its length, thus increasing the spark gap.

A high-tension magneto usually has two windings on its armature which is of the ordinary shuttle pattern.

An alternating current is induced in the primary winding, giving one complete cycle per revolution. This low-tension current is interrupted, as in the case of the battery system previously described, by a make and break contact with a condenser connected up across its terminals. This induces a high-tension current in the secondary winding in the usual way which is distributed to the various ignition plugs in their proper sequence.

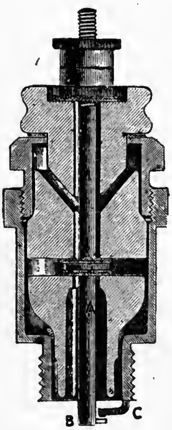


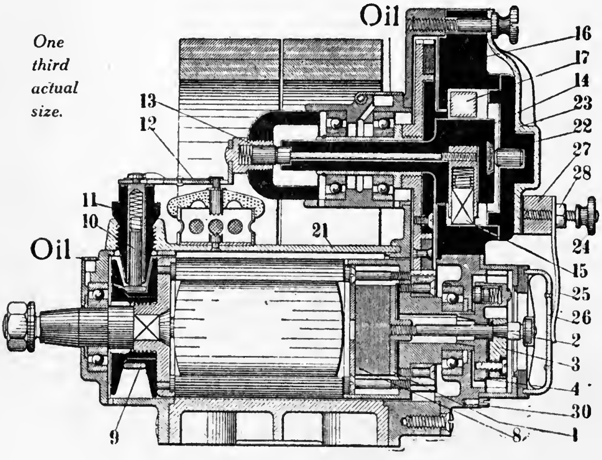
Fig. 43.—Sparking Plug for Magneto System.

The practice in the Bosch magneto is to retain a fixed armature and to displace the magnetic field by means of an induction sleeve. This sleeve revolves between the armature and the pole faces, thus distorting the magnetic flux through the air gap between the pole faces and the iron core of the armature.

This distortion sets up induced currents in the armature winding in the same way as would be the case if the armature itself were revolved. The magnets are usually made in three pairs of horseshoe-shaped steel with separate pole faces of cast iron. The pole faces are secured to the bedplate by screws passing upwards from underneath. The ends of the armature sleeve are held in brass end plates which form suitable bearings.

1. Brass plate.
2. Contact-breaker screw.
3. Platinum screw block.
4. Contact-breaker disc.
5. Long platinum screw.
6. Contact-breaker spring.
7. Contact-breaker lever.
8. Condenser.
9. Slip ring.
10. Carbon brush.
11. Carbon holder.
12. Connecting bridge.

Longitudinal Section.



One third actual size.

13. Contact carbon.
14. Rotating distributor piece.
15. Distributor carbon.
16. Distributor disc.
17. Metallic segments.
18. Contact plug.
19. Fibre roller.
20. Timing lever.
21. Dust cover.
22. Cover.
23. Triangular clamp.
24. Nut for switch wire (short circuit).
25. Spring for fastening brass cap.

FIG. 44.—Bosch Magneto.

The ball bearings in the Bosch machine are so made that the outer race, which is carried by a brass cap, can be drawn off with this cap as a complete unit, thus leaving the balls together with the inner ball race on the armature spindle. Both high and low tension windings are as usual on the armature core in this machine, but the high tension, instead of being directly earthed, is connected to the high tension end of the primary winding so that the secondary is earthed through the primary winding.

Condensers have been referred to as storing electricity in a static form. Every condenser has a certain capacity, which is, relatively speaking, very small as compared with say, that of an accumulator. Electricity does not flow *through* a condenser, but a certain difference of potential is set up between the two sets of elements of which it consists. These elements are made of tin foil insulated by inserting mica, wax, or wax sheeting between each one, alternate elements being connected together electrically and to the two terminals of the condenser. In the Coates system the condenser plays a very considerable part, this system being a radical departure from the usual type of magneto. This machine is driven by a belt from the engine and, therefore, is not set in any definite position as regards the relation of the crankshaft to the magneto

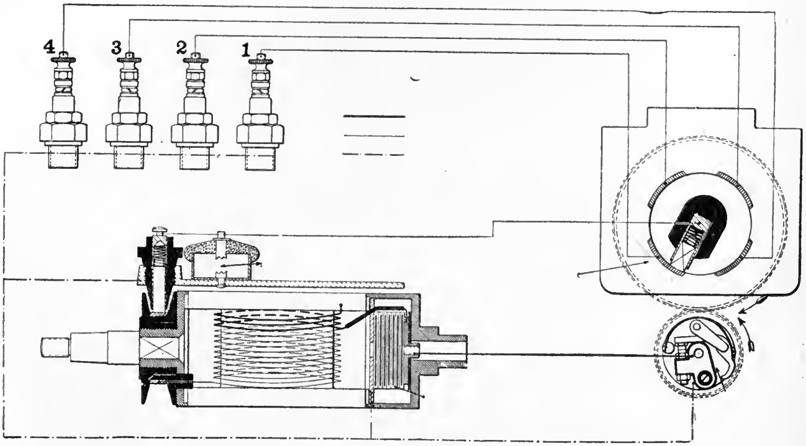


FIG. 45.—Bosch Magneto Wiring Arrangement.

armature. As the condenser discharges itself when the electrical pressure from external forces falls below its pressure, means must be provided in this system for maintaining the charge in the condenser until such time as it is required. For this purpose a commutator is connected up in circuit and the condenser is charged when the maximum voltage is generated in the armature; this is commuted

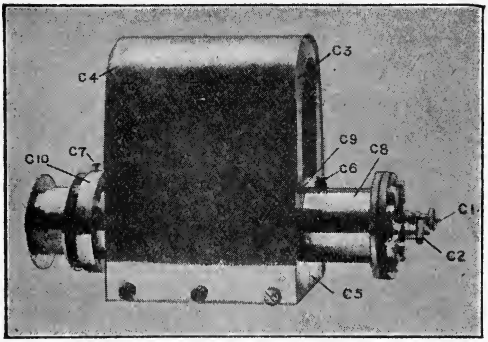


FIG. 46.—Coates Magneto.

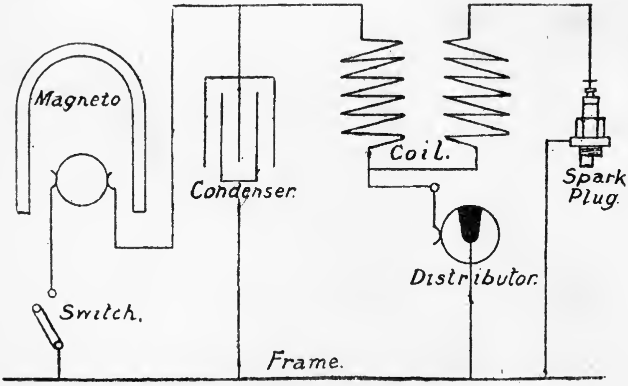


FIG. 47.—Coates Magneto. Diagram of Wiring for Single Ignition (1 Cylinder).

so that no change of polarity occurs at the terminals of the condenser when charging. The speed of rotation of the magneto is arranged so that the condenser receives about three of these charges for every time it discharges into the coils, and it can be used in conjunction with an ordinary battery system, the only additional part required being a two-way switch.

The contact maker is driven from the engine shaft and times the discharges from the condenser through the coils in the usual way, the high-tension windings being connected to the plugs at one end and earthed at the other end. The rapidity of the discharge eliminates any necessity for the use of trembler contacts on the coils ; these may be screwed down hard, but even with the ordinary adjustment the blades will be uninfluenced by the passage of the current.

CHAPTER XVII.

CARBURATION.

We will consider the question of carburation in the broad sense of the term, not only as applied to the use of petrol, but, in a certain degree, as regards other liquid fuels. The whole question will be considered from the point of view of an engineer rather than that of a chemist, for the reason that automobile engineers depend upon carburated air for the fundamental existence of their products and work. In this respect they differ from any other branch of engineering science, in that practically their whole base is dependent upon one type of fuel treated in one particular manner. Mechanical engineers in other branches of the science have many bases from which to work, such as wind power, water power, and steam power, either directly applied, or through the medium of electricity. Automobile engineers appear content to strive for perfection in detail of construction of individual products, and, at the same time, their fundamental base, their source of energy, is in a precarious state, more so, perhaps, than many are aware.

The author wishes to put forward as forcibly as possible the great importance of an organised investigation of the carburation question and its possibilities. Although many enterprising motorists have made individual experiments in this direction, the author amongst the number, it is only by treating the subject in a far wider manner that practical and beneficial results can accrue to the motor world at large.

Possible fuels may be divided into two classes, viz., the paraffin series, and substitutes. Of the former the distillate known as petrol is the base alluded to in the opening remarks of this chapter, and we cannot for a moment fail to see the enormous effect a serious shortage of petrol would have at the present time. There is no doubt that the fact that petrol has become the universal fuel for motor purposes is owing to its great adaptability, its cleanliness, ease of manipulation, and, comparatively speaking, wide limits of range as regards proportions of air and vapour within which it is possible to ignite the mixture.

The name "Petrol," however, is scarcely distinctive, and does not in any way define the properties of a liquid fuel. It may designate a spirit distilling completely at any temperature between 40 and 150 degs. Cent. Such spirits as these will completely evaporate at ordinary temperatures without leaving a residue when properly refined, but the only apparent difference between the two extremes is the time taken to effect complete evaporation.

As far as a petrol is concerned, the time element has some bearing upon the question of carburation, for, in a motor car, when the load upon the engine may vary enormously from moment to moment, the rapidity with which the carburetter responds to the demands made upon it is a great factor in determining the flexibility of the engine.

The author has made a number of experiments upon the rate of evaporation of petrols of different densities in order to establish certain facts which determine the rate of carburation of air and evaporation of petrol.

For the first series of experiments a car was taken and a draft gauge, to read in tenths of an inch of water, was fixed on the dashboard. The pipe by which the gauge was actuated was connected to the carburetter immediately below the jet. Without in any way altering the arrangement of the carburetter, the engine was run driving the wheels only, which were jacked up from the ground, the speed of the engine being fairly accurately determined by means of a small dynamo and ammeter.

The following table shows the results arrived at, the experiments being arranged so as to maintain a predetermined suction in the gauge, and the engine speed regulated to keep the suction constant:—

Engine revs. per min.	Suction in tenths of an inch Water Gauge.
360	5
480	7·5
600	10
680	12.5
820	15
1,000	20
1,250	31

When these results had been arrived at, the car was taken to a level piece of road and driven between milestones, keeping the gauge as constant as possible from one milestone to the next, and the time taken to cover each mile noted. As the clutch was not disengaged, it became an easy matter to check the engine speeds as given by the electrical method by reckoning the number of engine revolutions per mile and dividing by the time taken.

These results agreed fairly well, but the highest reading was not obtainable on the road, owing to the prevailing road conditions.

The results of these tests show, firstly, a progressive reading giving as the curve a practically straight line, and, secondly, that in a well-designed system of induction pipes and carburetter there need be no excessive wire drawing of the explosive mixture or of the air in the induction pipe.

Next to the consideration of the velocity of the air, as a factor in carburation, comes the manner in which the air meets the petrol, and this is dependent upon the arrangement and type of the carburetter.

Considering the three types of carburetter for petrol, we have the wick carburetter in which a natural system of carburating the air introduced is employed ; this is termed the surface carburetter.

This apparatus consisted of a small tank in which a number of wicks was fixed, and into which petrol was fed from the main tank. Capillary attraction caused the petrol to flow to the top of the wicks in the ordinary way, and the stream of air which the engine sucked over the surface of the wicks caused volatilisation. Selective evaporation does not therefore take place when wicks are used, as the heavier fractions flow up the wicks as readily as the lighter fractions.

It is obvious, therefore, that only petrol of a low boiling point can be used successfully in this manner, as no mechanical action takes place in the surface carburetter. Hand regulation operating a slide on the inlet pipe was necessarily required, in order to admit more or less air directly into the mixture, to compensate for variations in the rate of volatilisation of the liquid petrol.

Jet Spray.—The next step in carburation was the means of disintegrating the particles of liquid to a greater or less degree so as to assist volatilisation. This system is in general use at the present time in the form of a jet, which has one or more fine holes through which the petrol flows. The flow of petrol from the jet in such a semi-mechanical carburetter is not perfectly under control, but is affected by the inertia of the petrol in the jet and by the suction of the engine. The jet is placed in a contracted opening in the carburetter, preferably in a cone of a certain taper, the effect of the cone being to still further rarefy the ejected particles of liquid.

If a cone is not employed, a choke tube or other similar device is often very useful, as the required size of tube can be fitted to suit any abnormal condition in the atmosphere or density of the fuel. When this arrangement is adopted, the necessary air is drawn up around the jet, inducing the petrol to follow it in the form of a spray, part of which immediately volatilises, the heavier fractions being carried along the induction pipe into the engine cylinders in the form of a mist.

There is also a variation of this system, which consists of an arrangement of the jet at right angles to the air stream. This makes a very simple form of carburetter and combines a throttle, which, when in action, deflects more or less air into the vicinity of the jet.

Control of Mixture.—A choking of the quantity of petrol passing has been attained by placing a resistance to the flow of petrol in the small passage between the float chamber and the jet. This resistance is in the form of a spiral of a particular pitch or a notched bar. The friction of the petrol in traversing this obstruction has a retarding effect upon the velocity of the petrol, so that instead of a small increase in the velocity of the air producing a large flow at the jet, only sufficient petrol can pass to fulfil the necessary requirements. It will be noticed what a complicated series of operations must be considered, as the suction at the jet and the consequent flow of petrol which the air in passing produces is not directly proportional to the amount of air passing. Any spring made is proportional in its movement; that is, the range of elongations or compressions obtained are directly proportional to the load applied. Spring control is at the best, therefore, a compromise. Auxiliary air inlet valves do in a measure reduce the suction at the jet when the engine runs at higher speeds, but it is impossible to attain the correct proportions of air to petrol at *all* speeds by means of a spring contrivance.

Thirdly, we have the **mechanical carburetter** which depends chiefly upon the mechanical action of a pump or spray producer to effect carburation. A purely mechanical carburetter, in which the feed of fuel can be accurately measured and delivered to the engine, has a much wider range of possibility than an ordinary jet or surface type, for we find that many fuels of a negligible volatility can be effectually disintegrated by mechanical means and thus produce a mixture of air and a fine spray of fuel which is suitable for use in an internal combustion engine.

It is quite possible by mechanical or semi-mechanical means to produce a spray so fine as to be in the form of a mist, the desired effect being attained by forcing or sucking the air through a very thin film of petrol. The principle is shown in some forms of garden syringe used for delicate plants. In this syringe the rose consists of very fine holes. Water has to be forced through these holes under slight pressure whence it issues as mist. An adaptation of this principle to a carburetter enables the less volatile fuels to be successfully utilised, as, if we can finely divide the particles of fuel, each particle vaporises to a small extent, and, owing to the fine division of the whole, can assimilate sufficient oxygen to enable the flame to be rapidly propagated throughout the mixture.

The third point or determining factor in carburation is heat.

The Effect of Temperature.—Although petrol will completely evaporate at ordinary temperatures when exposed to the air, the time taken to completely disappear depends upon the final boiling point of the liquid. The lighter fractions of the petrol will come away quickly, and, therefore, when the fuel has a low final boiling point, no external assistance is required, such as the application of heat. The higher the final boiling point is raised, the greater is the difficulty of consuming the whole of the liquid; the heavier fractions must either be assisted in their volatilisation by means of heat, or in their atomisation by mechanical means.

The volatilised portions of the petrol may carry over the heavier in the form of suspended particles, when these heavier portions exist, and, assuming that they are not precipitated in the inlet pipe, they will burn in the engine cylinder. But when a large proportion of the fuel consists of fractions having a high boiling point, such as in the case of Borneo spirit which completely distils at temperatures from 170 to 200 degs. Cent., it is very advisable to assist carburation by means of heat. The author made many experiments with the object of determining the rate of evaporation of petrols of different boiling points and noticing the effect of heat and air velocity. A very simple apparatus was prepared, but it was sufficient to demonstrate the points in question. An electric fan, having variable ranges of speed, drew air over the flame of a small furnace, an anemometer of ordinary type was employed to determine the velocity of the air, and a thermometer was suspended in the stream of hot air. The temperature of the air could be regulated by the distance of the fan from the furnace and by the rate of revolution of the fan. Strips of white paper were suspended in a row in the line of the air stream. The petrols to be tested were dropped upon these strips of paper. Practically the same quantities of each were used in each comparative set of tests. Under the prevailing conditions it was easy to determine with fair accuracy the moment of complete evaporation. The results of these experiments are given in the next chapter.

Saturation.—When a body of liquid fuel, consisting of fractions having various boiling points, is exposed to a current of air either passing over the surface of it or bubbling up through the body of it, a selective vaporisation takes place. The lighter portions are first evaporated, leaving the mass of fuel containing heavier fractions. If, now, fresh fuel is added in proportion to that evaporated, the vapour arising will differ, as the fuel under treatment becomes denser owing to selective evaporation. For this reason a surface carburetter cannot give a uniform gas. Sorel has experimented very extensively with hexane,

C_6H_{14}, which corresponds approximately to the light 0.680 sp. gr. spirit, and his figures show the effect of temperature upon the quantity of fuel vaporised.

This fuel has a molecular weight of 86, a volume of it being that times the weight of an equal volume of hydrogen. The specific heat of hexane is 0.50, and its latent heat of vaporisation being 117 calories per kilogramme = 235 B.T.U. per lb. The vapour density or weight of a cubic metre of saturated vapour = 3.853 kilogrammes. Now, 100 litres of dry air at a temperature of 10 degs. Cent. and a pressure of 760 millimetres of mercury, being that of the atmosphere, was taken, and the air allowed to bubble up through the liquid at different temperatures. The quantities of hexane vaporised in each case are shown in the following table :—

Temperature of Air.		Grammes of Hexane Vaporised.
Cent.	Fahr.	
12.2	54	29.44
14.8	59	30.63
16.0	61	31.32
18.0	64	32.50
20.0	68	35.37
22.0	72	36.10
24.0	75	37.74

These figures show that as the temperature of the air is increased, a greater quantity of the fuel can be held in suspension by the air in the form of vapour. Such a vapour is said to be saturated, and any fall of temperature will cause the liquid to be precipitated in the containing vessel.

The lower calorific value per kilogramme of—

Hexane is	10,600 calories, or	19,100 B.T.U. per lb.
Heptane is	10,700 „ „	19,250 „ „

A perfectly combustible mixture of any of these vapours and air contains the same heating value per unit volume whatever the fuel may be.

The products of combustion are given in the following table, when the fuel is burnt with its theoretical quantity of air :—

Fuel.	Molecular Weight.	Products of Combustion corresponding to 1 lb. or 1 kilogramme.		
		CO_2.	H_2O.	N.
C_6H_{14}	86	3.069	1.467	11.825
C_7H_{16}	100	3.080	1.440	11.772
C_8H_{18}	114	3.085	1.432	11.736

Now, we can deduce the proportion of oxygen required to be mixed with the saturated vapour to form an explosive mixture, by ordinary chemical methods. These proportions must be such that the propagation of the flame will be sufficiently rapid to produce complete combustion, and, consequently, what is commonly termed an explosion. When we know the chemical composition of the vapour, we must determine the proportion of oxygen that each constituent requires for its combustion. Fundamentally taking air as consisting of 21 parts of O to 79 of N by volume we see that 1 cub. ft. of oxygen is furnished by 4.8 cub. ft. of air, or 1 lb. of oxygen by 4.35 lbs. of air at 15 degs. Cent. So, calculating the quantity of air required to furnish the necessary oxygen for the complete combustion of 1 lb. of petroleum vapour of, say, 86 per cent. C, 14 per cent. H,*

1 lb. of H requires 34.8 lbs. air—

so 0.14 lb. H requires 0.14 × 34.8, or 4.87 lbs. air to burn it alone;

* This calculation is for Pennsylvanian spirit; see Appendix.

1 lb. C requires 11.6 lbs. air—

so 0.86 lb. C burned to CO_2 requires 0.86×11.6 or 9.98 lbs. of air for the C;

making a total of $9.98 + 4.87$ or 14.85 lbs., say 15 lbs. theoretically.

If the temperature of the air is 15 degs. Cent., and at atmospheric pressure 15×13.4 is equal to 200 cub. ft. of air approximately, required theoretically per pound of petrol, then it follows naturally that the greater the density of the gas the greater will be the amount of air required for the complete combustion.

In practice, however, as is the case where coal is burnt, about one and a half times the theoretical amount of air must be introduced on account of the nitrogen present, and, in the internal combustion engine, the burnt gases which remain in the cylinder. These inert gases materially reduce the velocity of propagation of the flame. We therefore require about 23 lbs. of air or 300 cub. ft. per lb. of vapour.

In order to obtain the best results from a gaseous mixture we must have the following conditions fulfilled:—

1. The two gases mixed in their proper proportions.
2. The temperature and pressure of the gases within fixed limits.

In practice the most economical mixture is arrived at by a system of trial and error well known to the majority of users of motor cars, as the conditions are scarcely identical in any two engines. Differences of working temperature and compressions cause considerable modifications to be necessary in order to obtain the ideal results, and these results are also affected by the presence of exhaust gases in varying proportions, according to the efficiency of the silencer employed.

In order to illustrate carburetter loss when this is reduced to a minimum, the following tables, worked upon the results of the Tourist Trophy Race of 1906, may be of interest. The figures are based on those given by

Colonel Crompton in his paper on "Modern Motor Vehicles," and the results have been extended in order to show what the carburetter loss was in the case of the winning car, and the car which used the least petrol, also the percentage in loss of thermal efficiency due to this cause. "Carburetter loss" here implies all losses which take place either owing to fuel passing through the engine in an unburnt or partially burnt state, as well as any loss through leakage or caused by "blow-backs" in the carburetter.

TOURIST TROPHY RACE, 1906.

	Winning Car.	Car Using Least Petrol.
Average weight, lbs. - -	2,743.5	2,627.75
" speed, m.p.h. - -	39.29	36.8
" net H.P. - - -	13.35	10.5
Total H.P. hours - - -	53.8	46.6
Petrol used, lbs. - - -	44.9	38.5
" used per net H.P. hour, lbs.	0.83	0.825

For the winning car, calculating upon a thermal efficiency for the engine at 21 per cent. and a mechanical transmission efficiency of 92 per cent., taking the calorific value of the petrol at 18,500 thermal units per lb., we have—

$$53.8 \times 33{,}000 \times 60 = \left\{ \begin{array}{l} \text{106 million ft.-lbs. given out by the} \\ \text{engine in the form of useful work done.} \end{array} \right.$$

$$\frac{106 \times 100 \times 100}{21 \times 92} = \left\{ \begin{array}{l} \text{550 million ft.-lbs. representing heat} \\ \text{taken up by the engine.} \end{array} \right.$$

$$778 \times 44.9 \times 18{,}500 = 647 \text{ million ft.-lbs. work in fuel used.}$$

By difference we have 95 million ft.-lbs. = loss in carburation $= \frac{95}{647} = 15$ per cent. of the fuel.

Total efficiency of engine, carburetter, and transmission

$=\frac{106}{647}=16.4$ per cent., and 15 per cent. loss in carburation $=2.46$ per cent. loss of efficiency.

Therefore, with perfect carburation and no loss of fuel, there would have been an efficiency of 18.86 per cent.

Considering the car using the least petrol the figures would become—

$46.6 \times 33{,}000 \times 60 =$ { 92.5 million ft.-lbs. representing useful work done.

$\frac{92.5 \times 100 \times 100}{21 \times 92} =$ { 478 million ft.-lbs. representing the heat taken up by the engine.

$778 \times 38.5 \times 18{,}500 = 555$ million ft.-lbs. work in fuel used.

By difference we have 77 million ft.-lbs. work lost in the carburetter $=13.85$ per cent.

Total efficiency of engine, carburetter, and transmission $=\frac{92.5}{555}=16.65$ per cent., and 13.85 per cent. loss in carburation $=2.31$ per cent. loss of efficiency.

Therefore, with perfect carburation and no loss of fuel, there would have been an efficiency of 18.96 per cent.

CHAPTER XVIII.

LIQUID FUEL.

THE use of the term "liquid fuel" implies that the fuel is supplied to the engine in a "liquid" as distinct from a "gaseous" state.

It does not necessarily follow that the fuel enters the engine cylinder in a liquid state.

Since the gas engine was a commercial machine, the advantages of the use of a liquid fuel for driving this type of engine became apparent, and at the present time these advantages have become so enormous that there is quite a likelihood of the liquid fuel internal combustion engine superseding a large proportion of the steam units now in use. Manufacturers are designing and building these engines in constantly increasing sizes, and it is, perhaps, still a debatable point whether large marine engines of this type can be successfully used or not.

Liquid fuels must not be considered solely as the products of petroleum, because the control of that market is in the hands of a very few large companies.

It is necessary to have one or more alternative fuels, in order that purchases of fuel can be made in an open market. It is, therefore, essential that engines designed for liquid fuel should be capable of being run on these alternative fuels without material alterations in their gear.

The manufacture of a national fuel, as distinct from an import from foreign countries, should receive every encouragement, as such a fuel could not be a monopoly, and it is reasonable to expect that its price would be maintained at a steady and low figure.

It is about ten years since the lighter fractions distilled from petroleum came into commercial use as a fuel in this country.

The same high-speed engine, which is the prime mover in the majority of motor cars of the present day, was at that time in a state of infancy, and liable to frequent breakdowns through small derangements.

It was a necessity that the fuel for such an engine should be of the simplest nature, as far as its manipulation and properties for carburation were concerned.

Distillers of these lighter fractions know well that the majority of failures and breakdowns in the early days of the motor car were attributed to the imaginary, or real, bad qualities of the fuel.

This light fuel had originally a specific gravity of 0.680, and was very volatile, as the type of carburetter then employed depended solely upon the volatility of the spirit to effect its purpose. The spirit of 0.680 sp. gr. here referred to might be considered to be hexane, as it was a mixture of this compound with the higher and lower members of the saturated hydrocarbons, and was represented by the formula C_6H_{14}.

The earliest types of carburetter for this spirit are described in the previous chapter.

The jet spray types of carburetters now generally in use are semi-mechanical in their action, and when dealing with petrol of a specific gravity of 0.720 can be made to give a certain amount of satisfaction, at any rate to control the proportions of petrol vapour to air within the limits of ignition throughout a large range of demand. This spirit is usually employed at the present time, and the ratio of carbon to hydrogen is nearly represented by C_7H_{16} (heptane).*

The Heavier Liquid Fuels.—In the year 1903 the

---

* See Appendix.

author first thought that a fuel of a heavier body than that which was being supplied at the time for use in the motor car would be of some practical value. He considered that it was unnecessary that the whole of the fuel should vaporise readily as had been the system of carburation by means of a surface carburetter, as such a carburetter had been almost entirely superseded by the jet spray type. He considered that the heavier bodied fuels could be perfectly successfully utilised by a device of this nature. At that time such a fuel as he required was not commercially available, so that his early experiments were carried out with mixtures of paraffin and the then commercial petrol. There were several disadvantages in this fuel, as the paraffin was liable to precipitate in certain portions of the containing vessels, and, particularly when standing overnight, was liable to charge the pipes and passages between the tank and the carburetter to the exclusion of any trace of the lighter fractions. It became necessary, therefore, to obtain a more homogeneous mixture than that which is made up of portions of a liquid having a specific gravity of 0.700 and others of 0.810. Tests of this mixture, however, were carried out over a lengthy period, and the results obtained pointed to the fact that such a mixture, which had a specific gravity of 0.755, was rather more satisfactory, as far as its results were concerned from the consumption point of view, than was the petrol alone, with the additional advantage of its being somewhat cheaper, the price of the paraffin at that time being in the neighbourhood of sixpence per gallon.

Following upon these experiments large samples were obtained of the heavier Borneo spirits which then became available, although there was no market in England for them at that time. The reason for this absence of market is now well known to the motoring public, as it has been pointed out from time to time during the last year or so that the specific gravity standard which was then adopted was no true indication of the merits of a liquid fuel.

The particular spirits subsequently tested by the author were the Borneo 0.760 sp. gr. and the Borneo 0.780 sp. gr. This latter, however, has not even yet been adopted by users of motor car engines, although the former is very largely used now, particularly for motor omnibus work. There is a certain peculiarity about heavier liquid fuels, which is this—that although the specific gravity may be greater by several points, it does not necessarily follow that the fractional distillation varies in like manner.

Considering spirits from the petroleum base, the various fractions given off at fairly regular intervals in the best known two brands, namely, 0.715 sp. gr. and the 0.760 sp. gr., and taking for instance Shell spirit and Shell Borneo spirit for comparison, we find that the first drop comes off the heavier at 6 degs. lower temperature than it does off the lighter, but that in certain stages the heavier spirit behaves somewhat more erratically, so that during this earlier distillation the temperatures are higher at which an equal fraction is distilled, but when about 70 per cent. of the whole has been distilled off, the temperatures at which the heavier fractions are distilled off are somewhat lower in the heavier spirit than in the lighter variety. Now, if we are dependent upon evaporation of the petrol alone, we see that any spirit which distils completely between say 50 and 150 degs. Cent., will behave in a similar manner under similar conditions, whatever its specific gravity may be. We find, however, that if we treat the petroleum through a larger range of distillation, and thereby obtain a spirit with a higher specific gravity than 0.760, namely 0.780, we must reach a temperature considerably higher than 150 degs. Cent., and the resulting spirit will not behave, therefore, as the 0.760 spirit, owing to the presence of those particles which have a higher boiling point. Now, it is in order to deal successfully with the heavier particles in the motor fuel that mechanical action has to be applied, and in the case of the tests which were referred to in the earlier part of this chapter, it was the mechanical action upon the paraffin which caused its suitability for combustion in the engine cylinder. The theory is that heavier particles which do not readily evaporate are carried forward in the induction pipe in the form of a fine spray, and assuming that the temperature does not fall in any part between the carburetter and the engine, these particles will be carried forward into the engine cylinder, and there rapidly compressed and ignited in the suspended form in the presence of the partially carburetted air. There is a limit as to the amount of the suspended fuel which can be utilised in this manner, for we find that a point is reached when certain particles will be carried right through the engine system, and if the exhaust is trapped and condensed, we find portions of unburnt fuel here which have been carried through in the manner indicated.

Turning now to a totally different fuel we will consider tar benzol. Now, this fuel has a much smaller range of boiling points than either of those previously referred to, namely, between 50 and 100 degs. Cent. for 90 per cent. benzol. It is obvious, therefore, that a fuel with boiling points within these limits will be very volatile, and, as far as carburation is concerned, will give no trouble at all in the ordinary apparatus designed for petrol, with the exception, of course, that owing to its higher specific gravity, namely, 0.875, a slight modification in the float chamber, such as the addition of a weight, may become necessary in order to keep the level of the petrol sufficiently high in the jet.

The distillation figures given in the table (page 177) have been obtained by Messrs A. Duckham & Co. Ltd., and from these it is obvious that the Borneo spirit of 0.760 sp. gr. is very similar in its volatility to the better known light American (Pratt's) spirit, the only real difference being in the greater percentage of carbon present in the former. This higher percentage of carbon is due to the presence of benzol.

The author's experiments in connection with petrols

TABLE COMPARING DISTILLATION POINTS OF VARIOUS SPIRITS AND BURNING OILS.

Percentage coming over at the various Temperatures shown.	Varieties Distilled.							
	Pratt's, Sp. Gr. 700.	Shell, .717.	Shell, .704.	Shell "Borneo" Spirit, .753.	Tar Benzol, .878.	Refined Peruvian Spirit, .729.	Rocklight Paraffin, .825.	White Rose Paraffin, .800.
	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.	Deg. Cent.
First drop -	43	50	49	43	50	50	100	76
5 per cent. -	50	62	55.5	59	51.7	57	142	142
10 " -	53	67	60.5	70	53	60	152	149
15 " -	55	71	64.9	74	54	65.5	160	159
20 " -	63	74	66.6	76	56	70.5	163	167
25 " -	71	78	70	77	59	75	170	175
30 " -	73	79.5	72.2	78	72	76	176	181
35 " -	75	82.5	75	79.7	75	78.5	180	188.5
40 " -	77	85	77	85	79	82	189	191
45 " -	80	87	80	91	80.4	83	195	196
50 " -	80	90	84	95	82	84	200	200
55 " -	81	92.5	87.2	94	82.7	85.5	210	205
60 " -	90	95	90.5	97	83	86.5	217	207
65 " -	100	97	94.4	98.1	84.5	87.5	223	210
70 " -	103	101	97.7	100	85	89.5	232	219
75 " -	108	104	103.3	102	86.7	92	238	228
80 " -	110	108	108.8	106	88	94	247	233
85 " -	130	112.7	115.5	110	89.1	96	260	242
90 " -	133	121.5	121.1	117	90	99	270	252
95 " -	134	140	140	132	93.8	102	296	258
100 " -	140	154	152	141	97	107	300	262

of high specific gravities have been confirmed by later tests made by others interested in the development of the internal combustion engine.

The object of the trials was the observation of the relative behaviour of the different fuels under road running conditions, and tests were made over long distances varying from 1,000 to 2,000 miles, and also over shorter distances upon level roads—taking units of 1 pint, or 1 gallon of fuel, in each case, and noting the distance covered by the car upon such a fuel allowance.

The chief features noticed were:—

1. Consumption in gallons per hour = C.
2. Miles travelled per gallon = E.
3. Speed of car in miles per hour = V.
4. Approximate weight of car and passengers.
5. Condition of road.
6. Behaviour upon the level.
7. Hill climbing.

Naturally, in tests of this nature, the conditions varied enormously, and a general average had to be struck, and the results deduced from an empirical formula constructed by the author for the purpose.

A variable Y, with a standard equal to unity, has been introduced for the purpose of taking into account the observed conditions of the road surface and load, before placing the various fuels in their relative positions in the table.

In the construction of the formula the author assumed that the useful effect of each fuel was proportional to E, the miles travelled per gallon; also to V^2, the velocity of the car in miles per hour, and inversely proportional to the rate of consumption = C.

As the speed did not vary to any marked degree, any error due to the assumption of V^2 is slight, but the results agree very well with those of the general observation upon the road.

V^2 was taken, as the author has found by experiment that above a certain speed the power required to propel similar cars against the air and other resistances varies approximately as the square of the velocity.

When the value by the formula is found for any particular fuel, it then becomes a fairly easy matter to deduct what one ought to find in practice as the consumption for various car speeds. It does not necessarily follow that different fuels compare directly as their values under this formula. That is to say that differences of speed are sometimes more marked, and the formula in some cases exaggerates the actual relative effects of certain fuels.

LONG TESTS.

	Sp. gr.	$\frac{E \times V^2}{C \times 1,000}$	Y.	Final placing. Col. 2 × Col. 3.	Conditions.
Borneo - -	.760	11.6	1.1	12.4	Fair.
Moto-naphtha -	.700	11.0	1.1	12.1	Good.
Pratt's, .715 - Paraffin, .810 -	.755	10.0	1.0	10.0	,,
,, ,,	.755	7.5	1.3	9.75	,,
Borneo, .760 - ,, .780 -	.770	7.4	1.3	9.6	Fair.
,, - -	.770	7.4	1.3	9.6	,,
Pratt's - -	.715	9.5	1.0	9.5	Good.
,, - -	.715	9.36	1.0	9.36	,,
Borneo - -	.780	6.85	1.2	8.9	Fair.
,, - -	.770	4.32	1.4	6.1	Unfavourable.
Pratt's -	.715	5.05	1.2	6.1	,,

SHORT TESTS.

Borneo - -	.770	10.1	1.1	11.1	1 gall.
Pratt's - -	.760	9.45	1.1	10.4	,,
Borneo - -	.780	6.4	1.1	7.1	¼ gall.
Pratt's - -	.760	7.4	1.1	8.1	,,
,, - -	.780	3.6	1.4	5.1	,,

Borneo 0.760.—Starts from cold and vaporises readily, the engine pulls very well and is lively in action. On hills it works well, and continues to give steady power when the engine labours on a long incline. It is economical in consumption and averages 21 miles per gallon in the author's car.

Moto-Naphtha.—French spirit is very similar in its effect to the above and averages 20.5 miles per gallon.

Pratt's 0.715 *and Paraffin* 0.810 in about equal bulk will not start from cold without priming the carburetter with petrol. After racing the engine a short time, however, it works well, but will not run the engine slowly without misfiring and precipitating the heavier oil. A hot spark is required or smoke may be emitted. When the engine is heated very little adjustment of the air lever is required, but it is sometimes necessary with a large variation in the speed of the engine. Consumption 20 miles per gallon.

Borneo 0.760 *and* 0.780 mixed in equal volume will not always start from cold, but a few drops of this mixture injected into the air pipe will always start the engine. It behaves in a similar manner to ordinary 0.715 petrol in running, and when once started no difficulty is experienced in restarting. It has a clean exhaust and makes no perceptible deposit in the cylinders. It is not so lively as the 0.760 alone on hills, but on the level the results are distinctly satisfactory. Its consumption works out at 20 miles per gallon. A hot spark makes a marked difference with this fuel.

Pratt's 0.715 under similar conditions gives 18 to 19 miles per gallon.

Borneo 0.780 will not start cold, but a few drops must be injected into the air pipe or cylinders. When the engine is hot it works well but is sluggish in ignition, requiring a hot spark well advanced. It gives good results on the level or undulating roads, but on hills the power flags rapidly when the speed of the engine is reduced. It is clean burning, and gives 18 miles per gallon as its rate of consumption.

Pratt's 0.760 *and* 0.780 had only been subjected to short tests by the author at that time, but these showed that the 0.760 will give about 18 miles per gallon. Further lengthy tests have given better results with the redistilled 0.760 Anglo's spirit, which is practically equal in value to the Borneo in the table on page 179.

Taking the heavier petrols the table gives some results of the author's experiments, and shows that Borneo 0.760 spirit gives a greater all-round efficiency in action than does either the lighter or heavier spirit. This can be accounted for in the following way. The 0.760 spirit, as has been before shown, contains fractions which distil over the same range of temperature as the 0.710 spirit, but owing to the greater percentage of carbon present in this spirit than in the lighter or American spirit, it is enabled to take up more air, and, owing to its greater weight, a gallon contains more thermal units of the heavier than the lighter spirit.

With reference to the next fuel, namely, the sp. gr. 0.770, this was a mixture in equal proportions of the 0.760 and 0.780, and here we find traces, of course, of the heavier fractions contained in the 0.780. It is evident, therefore, that some of these heavier fractions were not consumed as readily as they might have been, and this was particularly noticeable when the engine was running at a slower speed and consequently the mechanical action of the jet was less violent; it therefore did not break up the liquid into so fine a spray as was the case when running at a higher speed. This fact is again more marked when the 0.780 spirit was used alone—in fact, to such an extent that some of the steeper hills were only ascended with difficulty with this spirit, the carburetter being without a hot jacket.

The figures shown in the table give results of very lengthy experiments with mixtures of the light spirit and paraffin referred to at the beginning of this chapter. It will be seen that the addition of the paraffin by equal volume increased the mileage per gallon from 18 to 19.5. This was no doubt due to the greater weight of mixture per gallon, but it was noticeable that there was a certain amount of waste, owing to insufficient heat being applied to the carburetter, and also to misfiring at certain engine speeds causing blow backs in the carburetter, but the results generally were highly satisfactory for such a mixture.

Now, referring again to the table, it will be well to point out one instance of the adaptability of the formula employed, so taking the factor of a certain fuel and equating it to 10, we have the following results which agree very fairly with those which have been obtained in actual practice upon the open road with that particular fuel:—

E = miles per gallon.	V = miles per hour average.
16	39.0
17	34.7
18	30.9
19	27.8
20	25.0
21	22.7
22	20.6
23	18.9
24	17.4
25	16.0

The factor 10 employed in the working out of the above table applies to the 0.760 Borneo spirit, and by adopting this method to any particular fuel the use of the system becomes apparent.

It is useful to notice one other property of these fuels in testing as it has a direct bearing upon fractional distillation; that is, the rate of evaporation of standard small specimens under different conditions. In the previous chapter, page 166, the author described a means of testing all these types of fuels by air currents of different velocities and temperatures, passed over strips of white paper which are held against the light. It is then easy to see exactly when the particular fuel has completely disappeared as the light at that moment appears with equal intensity right across the paper in the nature of a grease spot photometer. In this manner the behaviour of petroleum spirits of a specific gravity of 0.720 and of 0.760 may be summarised and compared.

The rate of evaporation of the 0.760 Borneo spirit is practically the same as that of the 0.720 Shell spirit throughout its range, but the 0.780 Borneo spirit is slower in action under ordinary temperature, and in air velocity it takes about three times as long as the other to completely disappear, but when the air velocity is increased and the temperature rises, the time taken is only about twice that for the other two spirits. As far as the flexibility of the engine is concerned there is, therefore, practically no difference between the two 0.720 and 0.760 spirit, but in the case of heavier spirits than this, heat must be added or else a purely mechanical carburetter becomes almost a necessity in order to utilise the spirit successfully. See page 191.

TIME TAKEN IN SECONDS FOR COMPLETE EVAPORATION.

Temperature. Velocity, ft. min.	T=75° F. V=0.	=80° F. =200.	=130° F. =320.	=145° F. =450.
Fuel—				
Shell, .720 - - -	85	36	27	21
Borneo, .760 - - -	90	38	27	21
90 per cent. benzol - -	75	38	27	21
Commercial alcohol - -	280	170	95	60
Alcohol mixture - -	240	95	75	42

Larger samples of each fuel were taken in these experiments than in those in the following table :—

EVAPORATION TESTS.

Velocity of Air in Feet per Minute.	Temperature of Air in Degrees F.	Specific Gravity of Petrol. (Shell, and Borneo.)	Mean Time of Evaporation in Seconds.
Still - - -	58	.720	30
		.760	35
		.780	90
300 - - -	59	.720	22
		.760	26
		.780	40
240 - - -	95	.720	15
		.760	17
		.780	27
350 - - -	100	.720	14
		.760	16
		.780	25
350 - - -	160	.720	9
		.760	9
		.780	17
560 - - -	95	.720	12
		.760	12
		.780	18

CHAPTER XIX.

BENZOL—FUEL MIXTURES—ALCOHOL.

WE will first consider the question of benzol as it comes from the distillers, in the form known as 90 per cent. benzol. This 90 per cent. means that 90 per cent. of the liquid comes over in the process of distillation at a temperature of 120 degs. Cent. The amount of such a fuel which is available in this country is at the present time about five million gallons per annum, and it is chiefly produced in the manufacture of gas, and from the residual products from coke ovens. In order to recover benzol from coke, special recovery plant has to be put down for the purpose. If manufacturers of coke could see their way to adopt modern recovery plants, there is every possibility that within the next few years the supply of benzol in this country could be increased fourfold. The present price of this fuel in London is about ninepence to tenpence per gallon at the makers' works in the crude state, but there is always difficulty in removing a certain small proportion of foreign matter, which, however, does not prove harmful in the engine cylinder. The specific gravity of this benzol at 15 degs. Cent. is 0.885, with a boiling point of 80 degs. Cent. The total evaporation point of crude benzol is 145 degs. Cent., which shows that a certain amount of distillation is necessary in order to produce what is known as the 90 per cent. benzol. However, there is a large available supply at the present, equal to about 1,200,000 gallons per annum of what is known as the 65 per cent. benzol, the properties of which are that 65 per cent. distils over at the temperature before named. This 65 per cent. benzol is consequently somewhat cheaper than the 90 per cent. benzol, but it has nevertheless been used with great success for motor car purposes. As far as the mixture of benzol and petrol is concerned, we have very little to gain from the point of view of benzol, but from the point of view of the petrol we increase its proportion of carbon, by the addition of benzol, for benzol contains 91.3 per cent. of carbon and 8.7 per cent. hydrogen, and is represented by the formula C_6H_6, whereas petrol would be more nearly represented by the formula C_7H_{16}, and its composition is of the order of 84 per cent. C, and 16 per cent. H.* The calorific value of benzol is about 10 per cent. greater per unit volume than petrol.

Crude benzol contains 163,680 B.T.U. of heat per gallon, as against 157,142 B.T.U. for petrol, and has an explosive range of from 2.7 to 6.3 per cent., as against, roughly, 2 to 4 per cent. in the case of petrol. Benzol holds in solution about 150 grains of sulphur compounds per gallon. This sulphur inevitably produces an unpleasant odour in the liquid, also, to a very slight extent, in the exhaust gases, and it is somewhat difficult to nullify it by the addition of an aromatic oil.

When we compare benzol with petrol we find it is more like the heavier Borneo spirit than the American, as the Borneo spirit contains sometimes as much as 90 per cent. carbon in its composition, and it is in a measure owing to this higher percentage of carbon present that the fuel for complete combustion requires a slightly larger volume of air.

Benzol has certain advantages in the way of greater economy over either the Borneo or the American or lighter spirit when burnt in engine cylinders. Benzol will mix with petrol, but does not do so as readily as it mixes with alcohol, for benzol will dissolve in less than its own bulk

---

* See Appendix.

of alcohol. This denatured alcohol is now known as commercial mineralised spirit. Alcohol alone, as is perhaps well known, will not burn satisfactorily in the cylinder of the internal combustion engine. One reason for this is that it requires about 10 per cent. of its heat of combustion in order to produce evaporation, and although its specific gravity, 0.833, is less than that of the benzol, and apparently it evaporates readily when this is put to the test, we find that alcohol under all conditions is very slow in its evaporation, and even the addition of benzol does not very materially accelerate this unless the temperature is increased to some great extent.

The calorific value of methylated alcohol is about 11,300 B.T.U. per lb. as against 20,000 B.T.U. per lb. in the case of petrol, but there is always a percentage of water present in alcohol which reduces still further the calorific value. However, on considering the efficiencies of the two fuels, we find that the thermal efficiency in the case of petrol is about 21 per cent., and in the case of alcohol about 30 per cent. when burned in an engine cylinder. In practice the petrol rarely exceeds an efficiency of 18 per cent., whilst the alcohol motor runs much nearer its theoretical efficiency without difficulty. Now, although alcohol cannot be used successfully in the ordinary engine owing to insufficient compression, mixtures of alcohol and benzol can be satisfactorily employed, and the author has conducted a large number of experiments with various proportions of alcohol and benzol, and has obtained results which show some promise for the use of such a fuel. The difficulty about this mixture is that the effects may not be the same from day to day, that whereas one day the engine runs perfectly with a certain mixture of these two fuels, on another day it becomes very difficult to get any results at all, and this from no apparent reason.

Alcohol requires less air than petrol for its complete combustion in the proportion 5 to 11.8 for equal weights of fuel, and its latent heat of evaporation is 288 calories per kilogramme as compared with 160 calories in the case of petrol. This means that the engine must be kept somewhat hotter, and the extra air inlets closed or nearly so. In conducting the experiments, various proportions of alcohol were added to benzol, and it was found that when the mixture consisted of 75 per cent. alcohol and 25 per cent. benzol, the practical limits of working were reached, and with this mixture a fuel consumption of from 16 to 18 miles per gallon was obtained as against a somewhat greater mileage for ordinary 0.715 sp. gr. petrol.

The table in the previous chapter shows the length of time taken for the alcohol to evaporate, and also the effect on the addition of the benzol.

When mixtures of benzol and petrol were tested upon the road, the fuel consumption was at the rate of:—

Benzol and Borneo 0.760 petrol in equal volumes, 22 miles per gallon.

Benzol, 5 vols., to Borneo 0.760 petrol, 2 vols., 25 miles per gallon.

90 per cent. benzol alone, 26 miles.

All at car speeds of an average of 20 miles an hour.

These figures show that if benzol is obtainable at a reasonable price, it is an eminently suitable fuel for motor car purposes, and that there is very little to be gained either way by its admixture with petrol.

It is most important that benzol used for motor car purposes should be free from naphthalene.

CHAPTER XX.

CARBURETTERS AND THE FLOW OF FUEL.

THE carburetter is to the petrol engine as the gas producer is to the gas engine, or the boiler to the steam engine, namely, an apparatus which supplies the working fluid to the engine itself in its most suitable form.

There is this principal difference, however, that whereas the gas producer or steam boiler supply that fluid more or less in bulk, a carburetter supplies each charge as required by the engine—the action starts when the engine starts and stops in a like manner.

The analogy to the steam boiler goes one step further in that there is the liquid space or chamber, and that which is occupied by the gas or vapour. These two spaces in the modern carburetter are distinct and separate, but in the older type of surface carburetter the vapour was drawn away from the surface of a body of liquid. Nearly every modern carburetter is worked on the float feed system, there being a regulating chamber into which the liquid is fed from the main fuel tank; a small float, in rising or falling with the level of the liquid, opens or closes a needle valve, thus tending to maintain a constant level of fuel in the float chamber.

This system regulates the head of the fuel which is maintained in the jet tube when the engine is stationary, and regulates the flow of fuel to the jet tube when the engine is working and burning fuel.

The second or jet chamber, sometimes also a mixing chamber, is usually an annular space into which the jet tube projects; in some cases the air which is required to be mixed with the vapour is passed round the jet tube in a direction parallel to its length, in other cases the flow of air is at right angles to the tube. Whatever the direction of the air current happens to be in any carburetter, its influence upon the liquid fuel contained in the jet tube is to cause it to issue from the tube in a small stream. This is due to the fact that an air velocity is always an indication of a difference of pressure at any two points in the air stream. In the case of a motor car, the air velocity is due to the suction pressure, or pressure below that of the atmosphere, being formed in the induction pipe due to the displacement of the pistons. The functions of the jet tube are two-fold:—(1) To regulate the supply of fuel and to proportion it correctly to the quantity of air passing into the induction pipe. (2) To atomise the fuel as it issues from the orifice so that a mist, or very fine spray, is formed in the mixing chamber.

The fuel in the form of mist exposes its maximum surface to contact with the air, and thus enables each particle of hydrocarbon to combine with its requisite quantity of oxygen in the process of combustion. Mechanical mixing being the first step towards chemical combination in this case, a failure will result in unburnt fuel passing through the engine cylinders into the exhaust, where it may be condensed to its original liquid form.

The time occupied in this process of carburating is only a fraction of a second, and assuming that the rate of revolution of an engine is 2,000 per minute, the time occupied by admission and compression of the mixture, being that in which carburation must take place, is $\frac{1}{2000}$ of a minute or $\frac{1}{33}$ of a second. When fuel evaporates, a certain amount of heat must be supplied equal to the latent heat of evaporation of the fuel, and this is usually supplied by the incoming air. When starting from cold this is not possible, so that flooding of the mixing chamber has sometimes to be resorted to, as only the small proportion of lighter fractions will evaporate off at first. An excess of fuel is therefore required momentarily in order to start the action of the carburetter. Very low temperatures are soon reached when quantities of fuel are rapidly evaporated which may be as low as −10 degs. Cent. To avoid this, either an excess of air must be admitted, or the carburetter itself heated either by water or exhaust jacketing, the former for preference.

THE MINIMUM TEMPERATURES IN DEGREES CENTIGRADE AT WHICH MIXTURES OF FUEL AND AIR CAN EXIST AS VAPOUR.

Quantity of Air in Mixture.	Minimum Temperature for Air and Hexane Mixture.	Minimum Temperature for Air and Heptane Mixture.
	Degrees C.	Degrees C.
Theoretical quantity - - -	−17.7	3.6
,, ,, +20 per cent.	−20.6	0.7
,, ,, +40 per cent.	−24.2	−2.0

The addition of an excess of air results in the production of large volumes of exhaust gas, and loss of heat occurs equal to the weight of these gases passing away in unit time, multiplied by their latent heat and rise of temperature.

The incoming air should therefore be at a temperature not below 22 degs. Cent., in order that freezing may be prevented.

A very low temperature will also cause the incoming vapour to condense in the induction pipe, which deranges the proportions of the mixture actually passing to the engine.

The viscosity and **specific gravity** of the fuel affect its rate of flow through the jet tube, and these properties vary with the temperature of the fuel. As this temperature is increased, it becomes less viscous, and more liquid will issue through the same sized orifice in the same unit of time.

The effect of temperature upon the viscosity of the fuel is shown by the author's figures in the following table. These figures give the time taken for the same quantity to pass through an instrument under the same liquid head of 60 mm. at various temperatures.

FUEL: "ANGLO 0.760" SPIRIT.

Effects of temperature upon viscosity. Head over orifice = 60 *mm. Tests of sample quantity through instrument.*

Temperature.	Fuel: "Anglo 0.760" Spirit.	Petroleum Distillate between 150 and 300 degs. Cent.
Degrees Fahr.	Time taken in Seconds.	Time taken in Seconds.
58	270	400
75	255	390
90	220	375
110	180	...
120	165	...
135	150	...

In the second case a more viscous fuel than ordinary petrol is shown. As the temperature increased, the actual pressure at the orifice was reduced slightly, owing to the reduction of the specific gravity. The amount of this reduction can be deduced from the following table:—

FUEL TESTED: "ANGLO 0.760."

Temperature. Degrees Fahr.	Specific Gravity.	Temperature. Degrees Fahr.	Specific Gravity.
54	0.732	81	0.720
60	0.730	86	0.718
65	0.728	90	0.715
70	0.725	95	0.713
75	0.723		

THEORETICAL.

100	0.710	120	0.700
110	0.705	130	0.695

When benzol is used as a fuel, in place of petrol, it is found that at low pressures, benzol does not flow through a small orifice as fast as petrol, the reduction in quantity being almost proportional to the calorific values of the two fuels. Benzol contains about 10 per cent. more heating value than petrol, and the heat required to vaporise a unit quantity of each is, for benzol, 1.29 per cent., and for petrol, 1.41 per cent. of the total heat of combustion.

It has been found by experiment that 89.3 volumes of benzol contain the same quantity of heat as 100 volumes of petrol, so that the flow of fuel in each case should be in the above proportions. The author's experiments upon the rates of flow of these liquids through a carburetter jet orifice give the results shown in the following tables, and as the specific gravities of the various fuels varied, these have been corrected to equal pressures. It may be argued that the "head" only should be taken into consideration, but with fuels of various viscosities the friction of the orifice is influenced by the pressure acting upon the fuel. This is borne out by the fact that at higher pressures the rates of flow of benzol and petrol become more nearly equal.

When fuel is used in practice, the *suction* and not the *pressure head* is the ruling factor, and this former is the same whatever the nature or specific gravity of the fuel. In the following tables all these suctions are designated in terms of water head, and from curve, Fig. 48, these can be transposed to the air velocities to which they are equivalent. A practical maximum air velocity through the carburetter outlet is from 190 to 220 ft. per second. The former value is equivalent to a water head of 8.75 in. suction, and the latter to 12 in. of water head.

If, for comparison, water and "0.760 Anglo" spirit are passed through a jet orifice under a 12-inch head of each liquid in turn, the rate of flow of the water will be approximately 5 per cent. slower than that of the petrol; a visible indication of this is given in the form of the issuing stream.

The petrol flows in a smooth and uniform jet, whereas the water jet is ribbed or fluted. In the case of these higher suctions, the rate of discharge increases more rapidly than $\sqrt{h}$, and is more in direct proportion to the head or suction pressure. (See Fig. 52.)

TABLE A.—TIMES TAKEN FOR 2 OZ. OF LIQUID FUEL AT 55 DEGS. FAHR. TO FLOW THROUGH AN ORIFICE 0.95 MM. DIAMETER.

Fuel.	Specific Gravity.	Head over Orifice in mm.			Head of Orifice in mm., Corrected for Equal Pressures.		
		30	40	60	30	40	60
		Sec.	Sec.	Sec.	Sec.	Sec.	Sec.
"Anglo .760" - -	.730	77	70	50	77	70	50
Distillate from paraffin	.795	165	142	...	172	148	...
Benzol - - -	.885	105	97	76	116	106	80

TABLE B.—TIMES TAKEN FOR 2 OZ. OF LIQUID FUEL AT 55 DEGS. FAHR. TO FLOW THROUGH AN ORIFICE 1.2 MM. DIAMETER.

Fuel.	Specific Gravity.	Equivalent Head for Petrol, 120mm Benzol, 99 mm	Head for Petrol. 150mm. Benzol, 124mm.	Head for Petrol. 180mm Benzol, 148mm
		Sec.	Sec.	Sec.
"Anglo .760"	.730	62	35	30
Benzol - -	.885	75	37	33

TABLE C.—QUANTITIES OF BENZOL (sp. gr. 0.875) FLOWING THROUGH ORIFICES IN GALLONS PER HOUR. TEMPERATURE, 66 DEGS. FAHR.

Diameter of Orifice in mm.	Fuel Head, 120 mm. Equivalent Water Head, 105 mm.	150 131	180 157
	Gal.	Gal.	Gal.
1.0	0.775	0.94	1.07
1.2	1.21	1.36	1.55
1.4	1.83	2.06	2.25

TABLE D.—QUANTITIES OF BENZOL (sp. gr. 0.875) FLOWING THROUGH ORIFICES IN LITRES PER HOUR. TEMPERATURE, 66 DEGS. FAHR.

Diameter of Orifice in mm.	Fuel Head, 120 mm. Equivalent Water Head, 105 mm.	150 131	180 157
	Litres.	Litres.	Litres.
1.0	3.52	4.27	4.86
1.2	5.5	6.18	7.04
1.4	8.32	9.31	10.22

The relations between suction and air velocity can be well defined, as it is known that the velocity of air flowing into a vacuum can be calculated from the ordinary formula for falling bodies :—

$$V = \sqrt{2gh},$$

where V = the velocity in feet per second,

g = the acceleration due to gravity = 32.2 ft. per sec. per sec.,

h = the head of liquid in feet.

This formula enables a curve to be constructed from which the suction pressure in any portion of a car-

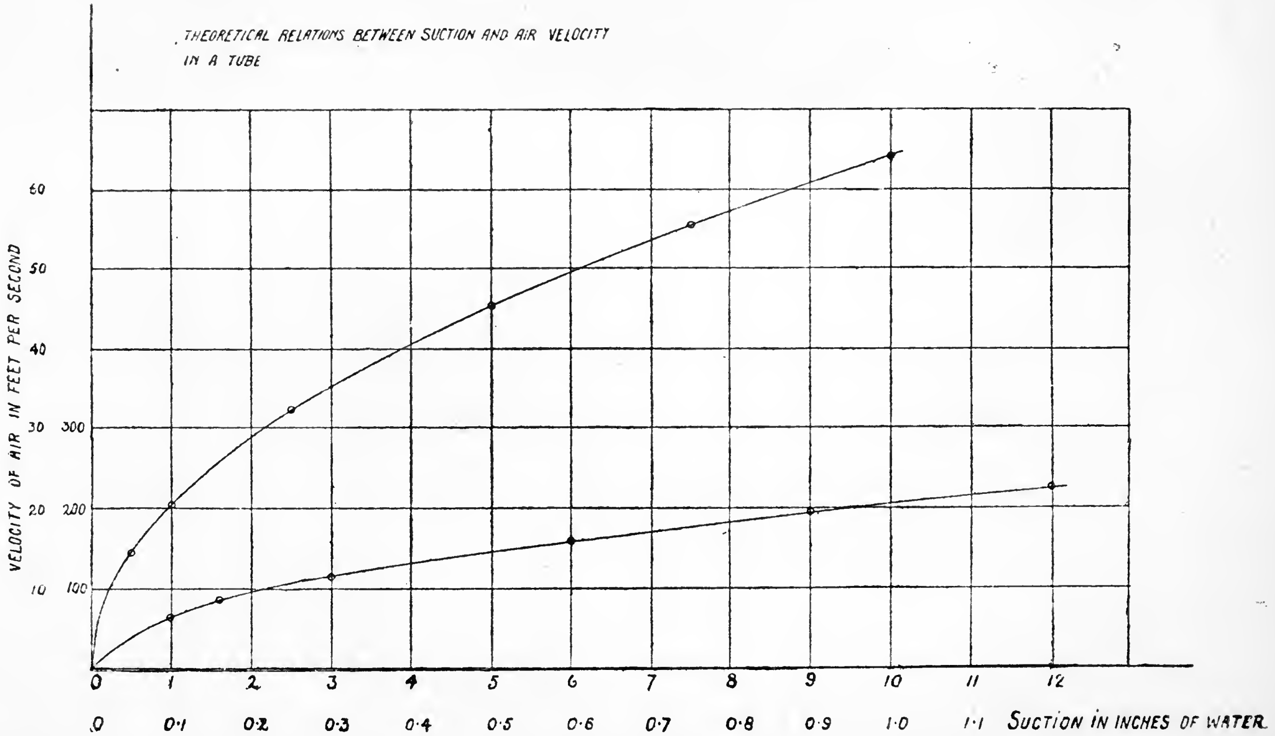


FIG. 48.—Curve $V=\sqrt{2gh}$.

buretter system can be calculated when its area is known, and also the volume swept out by the pistons in unit time.

The curve is constructed to two scales, the abscissæ being ten times the scale for low values up to 1 in. of suction on the water gauge; the ordinates also are ten times the scale for the lower values than for the higher. This system of calculation may be applied to a Longuemare carburetter in the following manner:—

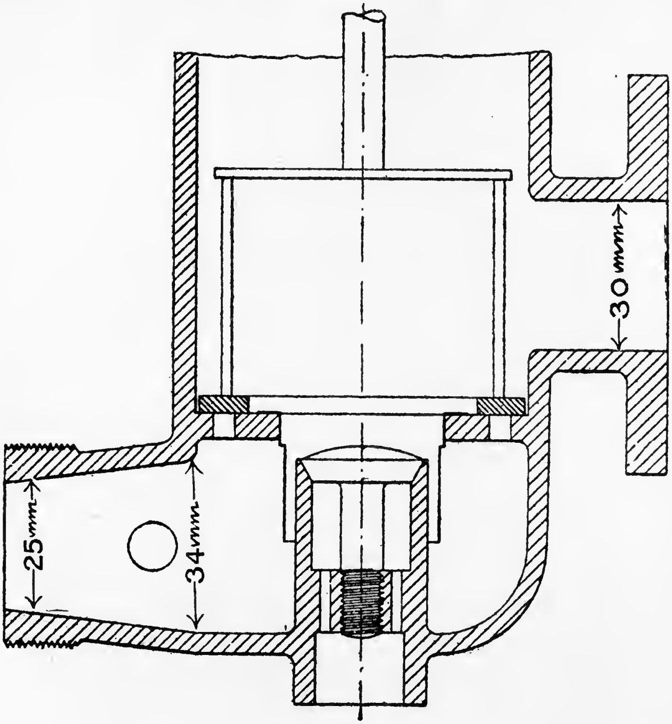


Fig. 49.—Longuemare Carburetter. Diagrammatic View of Type tested.

The air inlet of the carburetter with which the author's experiments were carried out was 30 mm. diameter at its

LONGUEMARE CARBURETTER EXPERIMENTS.

Engine revs. per min.	Suction at Inlet (area 9 sq. cm.) in Inches of Water.		Velocity of Air at Inlet to Engine side of Carburetter. Taken from Curve.		Velocity of air surrounding the Jet. Extra Air Inlets closed. Total Area of Passage = 1.74 sq. cm.		Suction in Inches of Water on Area of 1.74 sq. cm. *(calculated).	Velocity of Air with extra Air Inlets open. Total Area of Inlets = 5.4 sq. cm.		Suction in Inches of Water on Area of 5.4 sq. cm. *(calculated).	Suction in Inches of Water, at Main Air Inlet Area = 4.9 sq. cm. *(calculated).	Velocity in Feet per sec. Corresponding to Suctions in previous column.
	Experimental.	Calculated.	Metres per min.	Feet per sec.	Metres per min.	Feet per sec.		Metres per min.	Feet per sec.			
360	0.5	0.22	560	30	2,955	161	6.5	932	51	0.65	0.78	56
480	0.75	0.41	746	41	3,942	215	11	1,242	67.7	1.1	1.3	75
600	1.0	0.64	933	51	4,930	...	...	1,552	85	1.6	2.0	94
640	1.1	0.75	995	54.3	...	...	...	1,650	90	1.8	2.2	100
680	1.25	0.82	1,057	58	...	...	...	1,760	96	2.0	2.5	106
820	1.5	1.1	1,274	70	...	...	...	2,122	116	3.2	3.8	128
1,000	2.0	1.6	1,552	85	...	...	...	2,590	141	5.0	6.0	156
1,250	3.0	2.6	1,940	106	...	...	..	3,235	176	7.7	9.0	195
Col. 1	2	3	4	5	6	7	8	9	10	11	12	13

* By these calculated suctions the author signifies that the area has been taken and the displacement of the pistons in unit time divided by the area in the same units. The velocity then determines the suction by reference to the previous curve.

connection with the induction pipe. The main air inlet was 25 mm. diameter increasing on its way to the jet chamber to 34 mm. diameter. A tube was inserted into the taper portion, and readings were taken on a manometer attached to this tube. These readings were taken at various engine speeds while the car was driven at various uniform velocities over measured distances. The table on page 198 shows the results obtained in this manner.

The actual suctions obtained by experiment did not reach the higher calculated value, owing to air leaking into the carburetter through an extra air aperture. The aperture did not remain tight at the higher suctions, as shown in column 11. This column gives the calculated values for the suctions at the jet orifice producing the flow of fuel.

These experimental values give a flow of fuel some 20 per cent. lower than the calculated values taking the calculations as the mean of columns 3 and 11 for comparison, as the tube of the instrument was inserted about midway between these positions.

Additional apparatus was therefore obtained by means of which further cross checking could be carried out. A Claudel Hobson carburetter was next taken and a series of jet tubes of sizes varying from 0.95 mm. to 1.40 mm. in diameter. These jet tubes consisted of a small tube having a hole down the centre approximately 1.50 mm. diameter from one end to within about 5 mm. of the actual orifice. The remaining metal was drilled out exactly to the specified diameter marked on the tube. A small tank was fitted up having a tube screwed into the bottom projecting about 5 mm. into the tank, with a small point standing up about 1 mm. higher than the edge of the tube. This point served as an indicator of the level of the fuel and produced a surface tension before the fuel actually ceased flowing. The lower end of the tube was fixed to a tee piece into which jet tubes were screwed in turn. These tubes projected almost vertically upward, and had sufficient inclination to allow a free discharge without fouling the jet orifice and retarding further flowing of the fuel. Unit quantities were tested with different sized orifices under different fuel heads and the time taken in each case carefully noted. The level was maintained in the tank by noting the surface

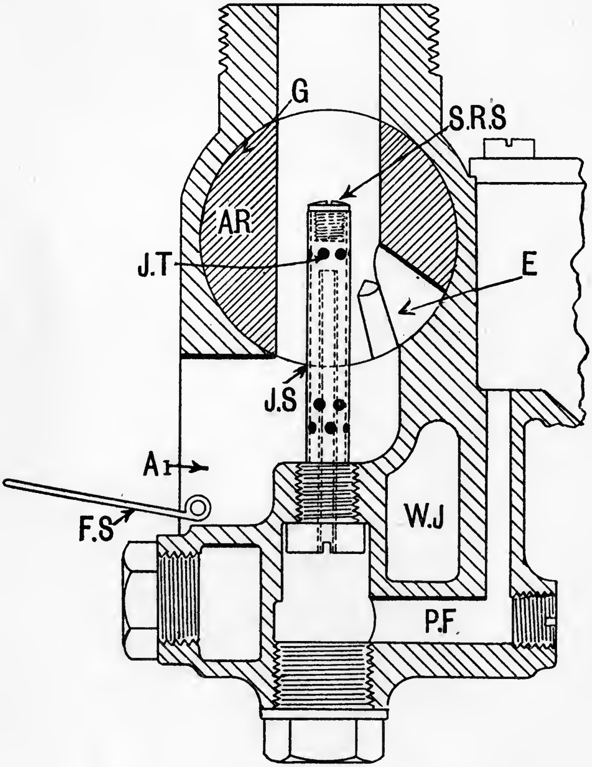


FIG. 50.—Claudel Hobson Carburetter.

A_1. Main air inlet.
A.R. Throttle for air and gas.
E. Specially shaped air inlet port.
G. Gas outlet port.
J.S. Sleeve round jet tube.
J.T. Orifices through which saturated vapour enters mixing chamber.
W.J. Hot water jacket.
P.F. Petrol passage.
F.S. Flap which can be closed when starting engine.

tension and pouring in fuel accordingly, thus preventing the ingress of air.

The smaller orifices at low pressure heads were erratic in their behaviour, the stream constantly breaking up into beads. This probably accounts for the difficulty of maintaining a very slow engine speed for any length of time with a jet tube of this description. The table gives the means of the results obtained with slight corrections in the lower values, these being increased to a small degree on account of the friction which occurred in the experiments.

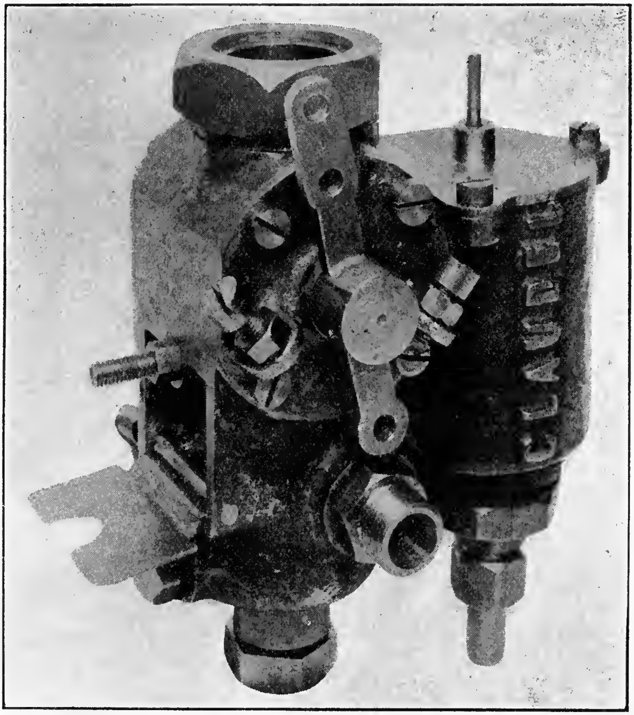


FIG. 51.—External View of Claudel Hobson Carburetter.

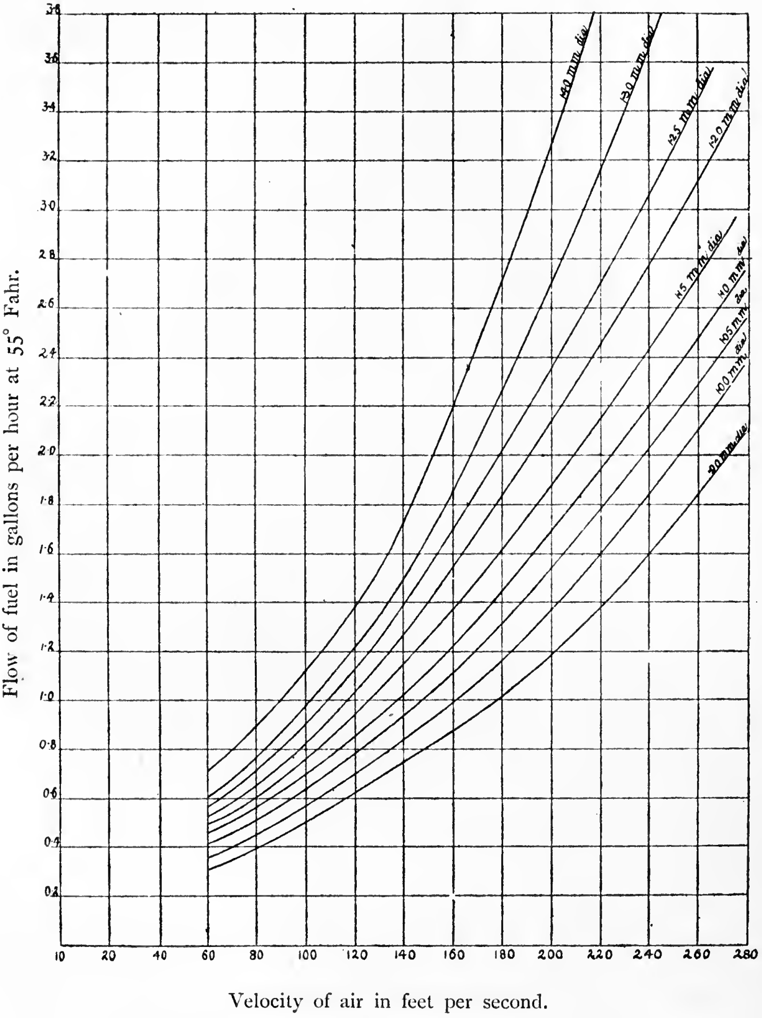
EXPERIMENTAL VALUES OF THE RATE OF FLOW OF LIQUID FUEL THROUGH PLAIN ORIFICES.

Diameter of Orifice in mm.	FUEL. Head in mm.	Quantity Flowing in Gallons per Hour = $Q=\frac{45}{t}$.	Time taken for Unit Quantity to Flow through = $t=\frac{3600}{80\times Q}$.	Diameter of Orifice in mm.	FUEL. Head in mm.	Quantity Flowing in Gallons per Hour = $Q=\frac{45}{t}$.	Time taken for Unit Quantity to Flow through = $t=\frac{3600}{80\times Q}$.
0.95	30	0.32	140	1.20	30	0.51	87
"	60	0.45	99	"	60	0.72	62
"	90	0.56	80	"	90	0.89	50
"	120	0.64	69	"	120	1.03	43
"	150	0.72	62	"	150	1.16	38
1.00	30	0.35	127	1.25	30	0.56	80
"	60	0.51	88	"	60	0.78	57
"	90	0.62	72	"	90	0.97	46
"	120	0.71	62	"	120	1.11	40
"	150	0.80	55	"	150	1.25	35
1.05	30	0.39	114	1.30	30	0.60	73
"	60	0.55	81	"	60	0.85	52
"	90	0.68	65	"	90	1.05	42
"	120	0.78	57	"	120	1.20	37
"	150	0.88	50	"	150	1.36	33
1.10	30	0.43	104	1.35	30	0.65	68
"	60	0.61	73	"	60	0.91	49
"	90	0.75	59	"	90	1.13	39
"	120	0.86	52	"	120	1.30	34
"	150	0.97	46	"	150	1.46	30
1.15	30	0.47	95	1.40	30	0.70	63
"	60	0.66	67	"	60	0.98	45
"	90	0.82	54	"	90	1.21	37
"	120	0.94	47	"	120	1.4	32
"	150	1.06	42	"	150	1.58	28

Fuel used, "Anglo .760" spirit. Temperature, 55 degs. Fahr.

When the fuel was heated to 70 degs. Fahr., the rate of flow increased in the manner shown in table.

FIG. 52.—BREWER'S CURVES SHOWING THE RELATION BETWEEN AIR VELOCITY AND THE RATE OF FLOW OF FUEL.



THE EFFECT OF TEMPERATURE UPON THE FLOW IN GALLONS PER HOUR THROUGH ORIFICES.

Diameter of Orifice in mm.	Fuel Head = 150 mm. Temperature.		Fuel Head = 180 mm. Temperature.	
	55 Degs. Fahr.	70 Degs. Fahr.	55 Degs. Fahr.	70 Degs. Fahr.
0.95	0.72	1.00	0.82	1.12
1.00	0.80	1.09	0.90	1.20
1.05	0.88	1.17	0.98	1.30
1.10	0.97	1.26	1.07	1.41
1.15	1.06	1.37	1.17	1.52
1.20	1.16	1.48	1.28	1.63
1.25	1.25	1.59	1.39	1.75
1.30	1.36	1.71	1.50	1.88
1.35	1.46	1.83	1.62	2.01
1.40	1.58	1.95	1.75	2.15

Application of Data.—When the rates of flow through an orifice of any dimension are known, it becomes a simple matter to reckon what suction is produced in the area surrounding the jet, as this suction bears a direct ratio to the quantity of liquid which passes the orifice. The petrol consumption can be measured by means of a small tank, and readings taken over known distances, keeping the engine speed constant. Thus a third method of arriving at the suction and flow is possible. The particular jet tube in the Claudel Hobson carburetter has an external sleeve perforated at each end, which has a balancing effect upon the local intensity of suction, by allowing air to pass through the annular space from a region of greater pressure. For instance, assume an engine to be running at 600 revolutions per minute. This may occur under two different sets of conditions; firstly, when the car is ascending a hill with throttle full open, the engine just manages to overcome the resistances, but its speed will not increase beyond 600 revolutions per minute. The throttle opening gives an area of 3.8 sq. cm., and the air velocity through this opening is 120 ft. per second, giving a theoretical suction of 3.4 in. of water (see Fig. 48 and column 14 in table, page 207). The experimental suction taken with a manometer at the throttle opening is 3.6 in. of water (see table A, page 206), which is within the limits of experimental accuracy. This produces a flow of petrol of 0.75 gall. per hour through the jet orifice, 1.05 mm. diameter in these tests.

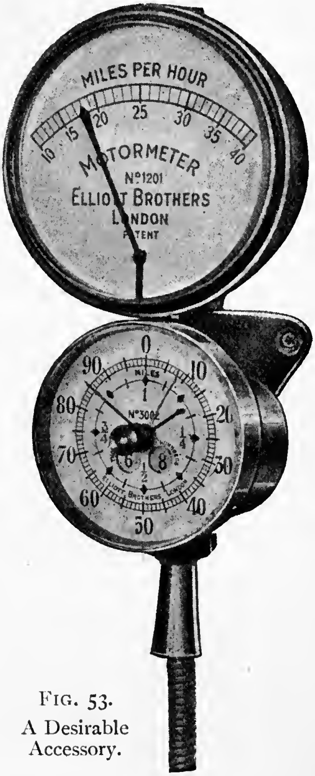


Fig. 53.
A Desirable Accessory.

Under the second set of conditions the engine may still be running at 600 revolutions per minute, but with the car on the level and the throttle half closed. In this case a somewhat smaller weight of air will enter the cylinders in unit time owing to wire drawing at the throttle, which has now an area of only 2.5 sq. cm. The velocity in this second case is 180 ft. per second if the cylinders are filled, thus allowing the same weight of air to enter; but the local suction at the throttle in this second case is produced by an air velocity of 180 instead of 120 ft. per second, corresponding to 8.1 in. of water. Owing, however, to the sleeve surrounding the jet, this suction is not reached, as the suction at the outer end of the sleeve is theoretically 0.60 in. of water. Taking the mean of these two, we have 4.35 in. of water as the probable suction at the jet, producing a flow of 0.77 gall. per hour, which is practically the same as in the first case.

The effect of this sleeve is clearly shown in table B, below.

TABLE A.—EXPERIMENTAL SUCTIONS IN INCHES OF WATER AT CARBURETTER INLET.

Miles per Hour.	Engine Revs. per Min.	Running Light.	Running on Level on Low Gear.	Full open Throttle. Top Gear.	
				On Hills	On Level.
		In.	In.	In.	In.
16	500	...	...	2.2	...
18	560	...	...	3.0	0.75
20	630	...	...	4.0*	...
22	700	1.4	...	...	2.3
24	750	...	2.2	5.5	...
25	790	...	...	6.0	...
25.5	800	1.6	2.5	...	...
28	880	...	...	7.0	...
28.6	900	...	3.6	...	4.4
30	940	...	...	7.8	...
32	1,000	2.3	7.0	...	...
33.3	1,050	3.0	...	8.8	6.0
37	1,150	5.0	...	9.5	...

TABLE B.—EXPERIMENTAL SUCTIONS AT THROTTLE IN INCHES OF WATER.

Miles per Hour.	Engine Revs. per Min.	Running Light on Second Gear.	Throttle full open on Top Gear.
		In.	In.
19	600	1.9	1.9
25.5	800	2.4	2.4
28	880	2.8	...
30	940	3.2	3.0
33	1,040	4.0	3.5
35	1,100	4.5	...
38.3	1,200	6.0	4.5
42	1,320	...	4.5

* 3.6 inches would correspond to a speed of 19.2 miles per hour.

CLAUDEL HOBSON CARBURETTER.

Miles per Hour.	Engine Revs. per Minute =N.	Velocity of Air at Carburetter Inlet. Area, 9.2 sq. cm.		Suction from Curve on 9.2 sq. cm.		Strangler Chamber; half throttle. Area, 2.5 sq. cm.				Strangler Chamber; throttle full open. Area, 3.8 sq. cm.			
						Air Velocity.		Suction (Theoretical).		Air Velocity.		Suction (Theoretical).	
		Metres per Min. =1.52×N.	Feet per Second.	In mm. of Water.	In Inches of Water.	Metres per Min. =5.6×N.	Feet per Second.	In mm. of Water.	In Inches of Water.	Metres per Min. =3.68×N.	Feet per Second.	In mm. of Water.	In Inches of Water.
11.5	360	548	29.8	5	0.21	2,016	110	70	2.8	1,325	72	30	1.2
13	415	632	34.5	7	0.29	2,320	126	111	4.4	1,528	83	38	1.5
15	470	715	39	9	0.37	2,630	144	127	5.0	1,730	94	48	1.9
19.2	600	914	49.9	15	0.61	3,360	183	205	8.1	2,205	120	86	3.4
25	780	1,187	64.7	25	1.01	4,360	238	...	...	2,865	156	150	6.0
27	845	1,286	70.4	30	1.2	4,730	258	...	...	3,105	169	180	7.1
32	1,000	1,520	83	38	1.5	5,600	306	...	...	3,680	206	260	10.2
35	1,094	1,605	91	45	1.8	6,125	334	...	...	4,050	220	290	11.5
40	1,250	1,900	103.6	61	2.4	7,000	382	...	...	4,600	251	...	...
Col. 1	2	3	4	5	6	7	8	9	10	11	12	13	14

TESTS FOR FLOW THROUGH ORIFICE 1.05 MM. DIAMETER.

Fuel used, "ANGLO 0.760," = 75 per cent. BENZOL, sp. gr. 0.88 = 25 per cent. Sp. gr. of mixture = 0.750.
Temperature, 70 degs. Fahr.

Duration of Test in Minutes.	Miles Covered.	Speed in Miles per Hour.	Fuel Used in Gallons.	Miles per Gallon.	Gallons per Hour.	(Experimental) Suction in mm. of Water.	Equivalent Water Head over Orifice producing Flows of Fuel in Column 6 (obtained from Table corrected for Temperature).	* Calculated Suction on Area of Throttle Assumed Full Open (obtained from Fig. 48).	Volumes of Fuel Admitted per 100,000 Volumes of Air at Cylinder Temperature and Pressure.
							mm.	mm.	
10	2.125	12.75	0.125	17	0.75	57	90	31	10.3
8	2.25	16.86	0.125	18	0.937	76	120	40	9.6
11	2.38	12.96	0.125	19	0.795	57	96	31	10.5
14	4.00	17.1	0.187	21.4	0.802	76	97.5	40	8.1
Fuel, "SHELL SPIRIT," sp. gr. = 0.715.									
6	2.38	23.8	0.125	19	1.25	140	179	114	9.0
5	2.25	27.0	0.125	18	1.5	178	236	137	9.5
Fuel, "ANGLO 0.760," sp. gr. = 0.730.									
5.5	2.38	26	0.125	19	1.36	153	212	126	9.05†
7	2.38	20.4	0.125	19	1.07	110	139	72	9.0
Col. 1	2	3	4	5	6	7	8	9	10

* For explanation, see page 198.

† 26 miles per hour = 816 revs. per min. Volume swept per rev. = 1,400 c.cm. per hour = 68.5 million c.cm. Volume of fuel per hour = 6,180 c.cm.; and the ratio of volume of fuel to volume swept out = 9.05 to 100,000.

The results of a series of experiments carried out over long distances are tabulated above and show the application of the methods of reckoning by calculation. It is not expected that the jet orifice thus determined shall be exactly accurate in every case and that no experimental work will be afterwards required, as no really exact determinations can be made for different sets of conditions. The base to work from is the proportion of liquid to air, and this varies with the compression of the engine and temperature of the air. The shape of the induction pipe also has some bearing upon the question, but the limits of accuracy should be within the limits of explosive range of the mixture, or say within 8 per cent., being 4 per cent. on each side of the best mixture. The majority of carburetters are not fitted with a balancing tube, but with some form of valve which opens as the suction increases, whose action is balanced by a spring. Such a device can only give correct mixtures at two or three points, as the effect of a spring controlled device is not coincident with the rates of flow of the liquid under varying conditions. The inertia of the liquid also affects its flow, particularly under large variations of speed and with a small number of cylinders. In the experiments before referred to, a mean has been taken when the speed of the engine varied. The resulting values are given in the tables.

Devices have also been tried in the form of resistances placed in the petrol passage between the jet tube and the float chamber. These consist of notched or spiral bars, which increase the friction upon the petrol during its passage to the jet tube. The effects of these retarders cannot be calculated and can only be obtained by experiment.

CHAPTER XXI.

MODERNISING A MOTOR CAR.

THERE must be quite a number of motorists in this country at the present time who took up the pastime in the earlier stages of the motor car industry. At that time several leading makers were turning out very excellent and serviceable cars for which they charged sums of money in accordance, no doubt, with their cost of production. In those days, however, it was very much more expensive to manufacture a motor car.

Firstly, we may consider that no standard form of car had been decided upon, and, therefore, the cars which were made, were not, as at present, put through the works in large groups—anything from ten upwards at a time, so that this and other modern methods had not tended to reduce the cost of manufacture. Some of these earlier cars were made absolutely to standard as far as the size of their parts was concerned, and the makers who then put them upon the market still hold stocks of spare parts. These spares can be obtained at any time, and will fit exactly without the necessity of a large amount of hand labour, which, even at the present time, may be called into operation in order to fit a spare part to the modern car. Now, seeing that the price of a second-hand car is so low, it seems almost a waste of capital to sacrifice a really good second-hand car for the small figure it will realise, as to replace it, we must add another fairly large amount of capital to the small price obtained for its sale. At the end of this how do we benefit? We may say we have a more modern type of car, perhaps a little more economical in its working than our old car, but in many cases the increased satisfaction from this small economy and more modern appearance must be bought at a high price.

An expenditure of this nature weighs somewhat heavily upon a man of moderate means, and this chapter is written to show that the above advantages can be obtained for a much smaller capital outlay.

When we look at the main points of difference between the modern car and the car of, say, three or four years ago, if this latter had been made of what we might consider an up-to-date design at the time, we do not find any radical differences in the general design.

Fig. 54.

The *chassis* of a modern car, however, is made much longer, and it is principally on account of the shortness of the *chassis* and the *tonneau* body that the older types of car are dated. We must, therefore, remove the body as a whole, and come to a decision as to the possibility of lengthening the wheel base by some two feet. This will generally be sufficient to allow a side entrance body to be fitted should it be so desired. If the car is of a live axle type, note must be carefully made as to the relative positions of axle and the back cross members of the *chassis*, and the length which may be added to the *chassis* will be determined to some extent by these relative positions. If it is found that by moving the axle backwards by the amount of two feet the differential casing might foul part of the *chassis* itself, this length must be either added to or decreased, in order that sufficient clearance will be given in a vertical direction when the axle moves over a rough road. A clearance of at least three inches should be allowed here, when the full weight is on the rear end of the *chassis*. Now, having fixed the amount by which it is intended to lengthen the *chassis*, it is as well to make a gauge so that every piece which requires to be lengthened can be made to this one gauge. Following the trend of modern design, it will generally be found that this lengthening of the *chassis* can best be accomplished by means of quarter elliptical springs, elongated in the thicker portion to give a good bearance upon the *chassis*, and the two longest plates should project some 2 in. beyond the thickest end of the spring in order to allow a bolt hole to be drilled for fixing. The brackets which support the forward end of the rear springs should be removed, together with the rear dumb irons, the new positions of the brackets be marked off by means of the gauge before referred to, and the holes drilled, care being taken that the new positions of the brackets are suitable, and that the metal to which they are fixed is sufficiently rigid. When the distance for lengthening the *chassis* is decided upon, these brackets must be well seated upon a strong portion of the side members of the *chassis*. Holes can then be drilled, and, if necessary, internal stiffening pieces fixed.

Next the rear dumb irons can be held in place and the exact dimensions of the new quarter elliptical springs taken. These springs should be made of a sufficient number of plates, certainly one more than the number in the existing rear springs, and a cross rod of circular section should be fitted as a distance piece passing through the eyes of the two springs provided with adjustable nuts inside. This cross rod should be carried through the spring eyes to a sufficient length beyond on each side to support the shackles which hold the rear ends of the old springs. The distance between the springs should be regulated in order that the two old springs should retain their same relative positions, and be parallel to the *chassis* as a whole. The projection of these springs should be carefully set out by means of one of the old dumb irons and the gauge previously referred to. When this is done, and the whole of the extension piece is in alignment, the two bolt holes, one to hold either spring, can be marked off and the holes drilled, and steel bolts fitted to clamp the springs in places.

Four strong steel clips should be made to fit over the springs, two to a side to clamp them right down to the side members of the *chassis*. These clips are of the same nature as those ordinarily employed for holding an elliptical spring on to its seat, but should be made amply strong, as they are always in tension. It is well to introduce a piece of hard wood or leather between the spring and the steel frame before finally clamping down. Steel keeps should be cut and drilled to fit across the ends of these clips, care being taken that they do not project too near to any part which may be in motion as the car moves along the road. Having now fixed the position of these springs, the other mechanism must be lengthened accordingly.

It will generally be found that a new cardan shaft has to be made. If this is a separate shaft and not made in one piece with the driving pinion, it is quite a simple matter to have a new shaft forged of steel suitable for the purpose. An arrangement such as this necessarily requires radius rods, and new radius rods will have to be made longer than the old ones by an amount equal to the length of the gauge. If, however, the cardan shaft and driving pinion are in one piece, and are enclosed in a sleeve which does the duty of radius and torque rods as well, this sleeve must either be renewed or lengthened. Perhaps the best and safest method is to lengthen the old sleeve, as it becomes a difficult matter to fix the old ends on to a new sleeve and keep them in perfect alignment at the same time. The best method of lengthening this sleeve, which is made of tubular steel, is to cut it in two, and to obtain a steel tube of an internal diameter slightly less than the external diameter of the tube which has been cut, and about 18 in. longer than the gauge. By this means the new tube can be bored or cleaned out and fitted over the old tube, giving a lap of about 9 in. at each end. This surface should be carefully cleaned and made a sliding fit, and at the same time two or four small pegs should be screwed into each end loosely. It will be necessary for this work to be firmly brazed together and it must be sent to a regular brazier who will make the whole thing into a solid mass. When this has been done and thoroughly cleaned, it can be replaced on the back axle, and the new driving shaft fitted. It is inadvisable to try and weld a length on to a special steel cardan shaft, as this is a most difficult job, and it is practically impossible with the majority of the best steels.

Now that this work has been completed, the whole of the axle may be assembled and put into place. It will then be found that small rods, such as those which compose the brake mechanism, will have to be lengthened accordingly by an amount equal to the gauge, and for this purpose new rods may be made, or the old ones cut in two and screwed into lengths of steel tube to bring them to their new dimensions. The whole of this work does not in any way interfere with the other mechanism of the car and is not at all a difficult or expensive job. At the present time, however, certain firms lay themselves out for this class of work, but if the car owner has moderate facilities, and, at the same time, an interest in his car, he will find it a pleasant and useful occupation.

When this part of the work has been completed, there will be quite a reasonable space available to fit a new body on to the *chassis*, and this can only be done by a coachbuilder. Any other alterations which may be desired to the ignition or carburettor could now be done before the car is finally painted, and it is advisable at this point to renew or replace any such features as may have become obsolete, and, if possible, to modify the lubrication system which is very defective in some of those older type of cars. It is also advisable to remove any unsightly drip feed lubricators from the dashboard, and to replace the whole of this system by one of a more modern and positive type. There are many forms of high-tension distributors which can easily be fitted without any material alteration to the arrangements for the ignition mechanism, and one of these might be fitted, with advantage, in many cases. At the same time, if the carburetter is awkwardly placed, a small alteration in the arrangement of the pipes will often make it more accessible, and it is as well, if possible, to take this opportunity of fitting a good steel apron to the under

FIG. 55.

part of the engine and gear box. If this work is done upon a really good car, which is perhaps only three years old, very much more satisfaction will be obtained than if the car is sold and the estimated cost of the above alterations added to the price obtained, and expended upon a new car.

CHAPTER XXII.

*THE CARE OF THE CAR.**

THERE is no piece of mechanism which has ever been designed and constructed for the use and service of man which is subjected to rougher or more unfair treatment, and is at the same time more generally reliable, than the modern motor car. When we consider the multiplicity of accurately made parts, the number of different materials, and the enormous and ever varying stresses to which these parts are subjected, it is more than a marvel that breakdowns on the roadside are not more numerous. Added to all this is the want of care which is too often displayed by owners and paid drivers alike, and the neglect of what should be considered essential observances.

In the following remarks and hints, the author hopes to put forward in a clear and concise manner certain facts which should be the creed and *modus operandi* of the real motorist—the enthusiast. Certain members of the trade will take exception to many of the points raised, in all probability, stating that in *their* cars such observances by the purchaser are unnecessary, and that all these points are carefully noted in the works before the cars are turned out. The answer to this is simply that mistakes may and do occur; foreign bodies find their way into vital parts of the mechanism, and only too frequently are adjustments badly made. From the purchaser's point of view it is extremely useful to know certain important features when

---

* By Permission of *The Car Illustrated.*

the car is new, so that from time to time these may be checked over and an indication obtained in a few moments of what has taken place during the running of the car.

A new car is bought, and the time has come for its delivery; before the purchase has been completed it is usual to take a trial run with a representative of the seller. Do not be disappointed if the car is not up to expectations at first; a new car is sure to smoke at the exhaust on account of the extra lubricant required, and is sure to be stiff in working, but always make a trial on a steep hill and see that *all* the gears are used. It sometimes happens that the first or second may stick in the shifting mechanism.

When the car is yours, and safely returned to the garage, the "care of the car" commences in earnest. Do not rush out at once upon a 200-miles' drive, if you intend to be in sympathy with the car. The garage space about the car should be sufficient to allow freedom of movement all round it, and every part of the car in turn should be carefully gone over. Starting with the radiator, remove any surplus paint from inside the tubes, if these are painted and of the honeycomb type, see that a strainer is fitted inside the filling plug and that a drain cock is fitted at the bottom, or failing this in the lowest part of the water circulation system. Notice the method of driving the fan, and whether there is a means of tightening the belt or other driving gear—it is very useful to fix a spring to keep a slight tension on the belt if possible, and be sure that a spare belt, or a portion with fasteners, is in the box of spares.

The method of driving the pump should also be noted, and the means of tightening the gland; spare packing for the pump gland should be carried upon the car, as this is apt to give out at an inconvenient moment. If the engine is run, the volume of the pump discharge, or the pressure upon the gauge, if fitted, should be carefully noted for future comparison.

Turning now to the carburetter, take the top off the float chamber and, if possible, expose the jet and notice the height of the petrol in the jet tube; this should generally be, say, $\frac{1}{16}$ in. below the surface of the jet orifice. If heavy petrol is to be used it is often advisable to weight the float. When the carburetter is filled with heavy petrol, the amount of the weight should be such that the petrol level will rise to its proper height. The reason for the necessity of the weight is that the increased buoyancy of the float in the heavier liquid causes the cut-off to take place before the proper level is reached in the jet tube. The weight required is somewhere about $\frac{1}{2}$ oz. with 0.760 sp. gr. petrol, as a rule, and may be in the form of a lead washer placed upon the float. When the float chamber top is replaced, depress the priming rod and notice the action of the spray for future comparison. Be sure a petrol filter is fitted in the pipe between the tank and the carburetter; if not, one can be bought or easily made—a piece of linen or flannel is a useful medium, and this should be renewed or cleaned from time to time. When the gravity feed system is employed notice that the vent hole in the tank stopper is free and not likely to become choked with waste or any other obstacle. The author strongly recommends that all petrol tanks should be fitted with the Nonex safety device. A careless person has often caused a car to be burnt up or the tank to explode, which risk will be greatly minimised by the use of this device, but be sure that a small hole is drilled in the stopper when used on the gravity feed system.

The Transmission.—This part of the mechanism of a car is perhaps the most hardly used, and, from an engineering point of view, the most unsatisfactory in the whole of a car's construction. The greatest losses take place here, and it is upon this mechanism that the most care should be bestowed. Considering a live axle type, and most of these remarks apply to the chain-driven types as well, the portion dealt with will comprise all the mechanism between the rear of the clutch and the road wheels.

First jack up one wheel of the car at a suitable point near the end of the axle. Then take the lid off the gear box and by manipulating the change speed lever, see that all the gears go properly into mesh, also carefully note that there is no foreign matter in the gear box. New cars sometimes have a nut left in the gear box. Take hold of the wheel that is jacked up, and carefully notice the amount of rotary motion in each direction, or the total swing you can give it before the cardan shaft begins to rotate. This will give a measure of the initial backlash in the differential and driving pinion.

Then repeat the process with each gear in mesh in turn, the extra swing obtained before the clutch rotates will be a measure of the backlash in the gear teeth. There should be none in the joints of the cardan shaft if well designed. These measurements should be carefully kept for future reference, as this process of testing the backlash should be repeated at regular intervals. It is very useful to remove the plug of the inspection hole in the differential gear box and notice the motion of the differential gear wheels. If a small rod is inserted, these wheels can be moved towards the centre and apart, and the amount of movement possible should also be compared from time to time. When the car is being driven, these wheels, when of the bevel type, are forced apart from the centre, and any rotation of the differential causes wear to take place on the backs of the wheels. If this becomes excessive the teeth only come into mesh at the points, and the driving stresses are only transmitted through the weakest part, instead of through the strongest part, of the teeth. If, owing to rough treatment or excessive wear, this state of affairs should occur, the axle must be taken down and the differential reassembled, the two halves of the differential gear casing can be let closer together, or new wheels fitted. It is most important that the star piece upon which these small wheels are mounted should be firmly gripped between the two halves of the casing, as the least movement will eventually cause the star piece to break and very serious damage will result. By differential gear case is meant the steel case which is inside the differential gear box ; this contains the differential wheels and the two bevel wheels with which they mesh. The latter have squares in the centre for driving the main shafts.

This casing is riveted or bolted to the crown wheel which is driven by the pinion on the cardan shaft. The relative positions of these two wheels is most important. It is sometimes possible to ascertain the amount of movement in a direction at right angles to one another between these two wheels without dismounting the axle, but in any event this should be carefully noted, and any excess taken up by means of a large washer behind the stationary half of the thrust collars when the axle is dismounted for the first time. It is usually necessary to allow about $\frac{1}{16}$ in. play, *i.e.*, when the driving pinion is in place, the crown wheel and casing can be moved $\frac{1}{16}$ in. backwards and forwards towards it in a direction at right angles to the cardan shaft.

There are three principal bearings here which require attention from time to time, and it is in many cases not an easy matter to ascertain their condition without dismounting. However, by means of a small rod placed through the inspection hole of the differential gear box, the casing inside can be moved slightly in a vertical direction, using the outer box as a fulcrum. This amount of movement should be scarcely perceptible, and gives the clearance of the two main bearings which support the crown wheel. The third bearing is that supporting the pinion on the cardan shaft, and this is as a rule impossible to test, but the end play can easily be tried by moving the shaft along its own axis by means of a small bar or screw-driver. The importance of maintaining an accurate adjustment of the transmission system cannot be overstated. An instance in point occurred primarily owing to the use of too thick an oil in the back axle. The three bearings were plain bronze, and by some means, the internal oil holes became choked by dirt or grease in the oil. The bearings soon scored severely, resulting in the teeth in the bevel drive being thrown out of their correct position. In a short time the points of the teeth on the cardan shaft became so thin that they would no longer drive the crown wheel.

After the worn parts had been renewed, a thinner oil was used, and no perceptible wear has taken place after 10,000 miles running. All gear wheels should be carefully examined from time to time, and the author's opinion is that the lubricating oil often employed in gear boxes is too thick or viscous. If gear teeth show a sign of wear it is policy to have them trimmed up and re-case-hardened, and the oil should be carefully cleaned out of the gear box to remove any metallic particles which may have accumulated.

It is advisable to clean out the differential gear box and the change speed gear box as soon as a new car has run a short time, as in the process of the journals or ball races becoming bedded down, small metallic particles are released and become mixed with the oil.

With regard to overhauling the gear box, first prop the clutch out of gear with a piece of wood, then, placing each speed in gear in turn, note the effort required to turn the transmission gear, first by manipulating the male portion of the clutch with the hand, and then from the other end of the system, viz., the wheel that is jacked up. Also be sure that, as each gear is in mesh, the amount of freedom which the sliding wheel has, allows it to move an equal distance on either side of the fixed gear wheel, the lever being in the notch, and if a dog clutch drives on the top speed be sure it goes properly home. No slackness of the main or countershaft bearings should be permitted, and it is better to renew these if they cannot be adjusted.

The joints on the cardan shaft should require very little attention, except the square types. These are apt to wear at the corners, and if not attended to give a nasty jar to the whole mechanism when the clutch is put into gear.

When separate radius rods are fitted to a car the correct length of these is most important, or undue wear will take place in the square joints of the cardan shaft. The object of these is to produce a correct parallel motion, and to transmit the drive from the road wheels to the *chassis*.

Some cars, however, drive through a sleeve surrounding the cardan shaft, and the thrust is transmitted through a thrust bearing in the gear box. As this bearing has a heavy duty to perform, it is apt to wear if not properly protected from mud and dust. This wear should be carefully tested from time to time in the same manner as that employed for testing the play in the cardan shaft, as detailed above.

Wheels and Brakes.—Place a second jack under the other driving wheel, and put on the side brake gradually until the bands begin to grip. This should occur at the same moment in each case, and at this time the lever should not be quite half way over its quadrant. The brake, when hard on, should grip both wheels firmly, and there should still be plenty of room in the brake lever quadrant for further movement.

The foot brake can be tried in the same manner. The author strongly recommends the use of the side brakes when driving, as these are usually of large surface, and transmit the braking effect through the least possible number of parts. A countershaft brake, on the contrary, reverses all the heavy stresses to which the transmission gear is subject. A ratchet sprag, if fitted, should be so arranged that it is impossible to put the reverse gear in mesh whilst the sprag is in action. When the brakes are off, both wheels should be perfectly free in action in both directions of rotation.

The wheels should all be tested for end play, and the back ones should show a very slight movement when two opposite spokes are firmly gripped. Front wheels are tested by holding the top of the wheel and endeavouring to rock it in a direction at right angles to its plane. There should be practically no perceptible movement, and at the same time, perfect freedom in the direction of rotation.

Sometimes the cardan shaft brake hangs on to the drum; if this is so, a spring should be fitted to take the weight of it. All superfluous paint should be removed from the joints of the brake gear and from all small pin gear, such as spring hangers; it is also advisable to remove and grease all such pins well when the car is new, and to repeat the process periodically. All small pins require inspection at regular intervals. The shackles of spring hangers should be oiled whenever the car is taken out. It is very convenient to have plate shackles bushed with hard steel, as these bushes can be renewed if necessary. Fortunately the lubrication of these parts is receiving more attention now than formerly, but one point is often overlooked, and that is the rear spring seats. There is a slight movement of these upon the back axle when the car is running, if radius rods are fitted (see page 127). The spring blades, too, should be treated with graphite or grease, but this is sometimes difficult to apply unless the springs are taken apart.

Graphite, too, is very good for the lubrication of chains. These should be taken down, well cleaned with paraffin, and immersed in a hot bath of graphite and tallow, so that the mixture may soak thoroughly into the joints. After this has been worked in well, the chain can be wiped clean and replaced. The chain bolt should not be too tight, otherwise a stiff joint will result.

Controlling Gear.—All controlling gear should be kept free in action, and have its full movement at all times without fouling pipes or other parts of the *chassis*. Brake gear or clutch gear should never come in contact with the controlling mechanism. If so, the rods, or levers, should be altered. In a case in point, a small rod came in contact with the petrol pipe when the former was in a certain position. After a few months the petrol pipe was worn through in a place difficult of access. Such faults as these do occur in some cars, as turned out by the makers, and should be remedied at once. Controlling mechanism which consists of rods and levers is liable to shake and rattle after some use. A small spring attached to one end of a lever will prevent this and prolong the life of the mechanism, as vibration will cause a steel rod to wear through in time. Hard rubber washers are also of service when placed behind an ordinary washer and split pin, and prevent any undue noise. Such apparatus as the distributor or commutator should be easy of access and its position should be clearly marked. It should be impossible to refix this at any time in the wrong place. If there is no guiding mark, one should be made at once. The flywheel should be marked in some convenient place to show when, say, the first piston is at the commencement of its firing stroke.

The Engine is generally the most satisfactory part of the whole car, and with reasonable care should outlast all the remainder of the *chassis*. The engine seldom requires taking down, but when the cylinders are removed for annual inspection, the heads should be freed from any deposit of carbon. The large and small ends of the connecting rods can then be tried by grasping the piston in the hands, and imparting a vertical pull. There should be some side play in the bearings of the connecting rods, but before taking up any brasses, try the shaft in different positions of rotation. The reason for this is that the journals sometimes wear slightly oval. The piston can easily be disconnected by removing the gudgeon pin, but there is usually no means of adjusting this bearing. The large end can be manipulated to a nicety, and the rod should swing freely in all positions before it is finally assembled. If much brass is removed from the flats of the bearing, a corresponding thickness of packing piece, drilled to take the bolts, must be placed between the brass and the rod end, in order to restore the compression to its original value. This packing must be very securely fastened.

It is most probable that there will be no appreciable wear in the crankshaft bearings, but this would in any case be an overhaul for the repairer or maker. Where there are several bearings in line, it is inadvisable to tamper with them. A bar should be placed so as to lever up the fly-wheel and test for slackness at this end, the forward end being tried by the hand. A careful motorist can remove the piston rings without risk ; this should be done, and the carbon deposit cleaned from the grooves before replacing. See that the joints in the rings of any one piston are distributed around its circumference, also that there is a fair amount of spring in the rings. Worn or weak rings should be replaced, for it is scarcely worth the risk to try and tap out an old ring unless one is accustomed to the process. In fitting a new ring, be sure that it is free to move in its groove—this can be tried without actually slipping the ring over the piston by placing the convex surfaces of both piston and ring together, and moving them round together.

Before replacing the pistons, the heads should be scraped, and this is a convenient time to take out the valves and grind them in. If a lathe is handy the cylinders can be taken bodily and placed upon the lathe bed, and the valves ground in by the lathe, more accurately than by hand. If there is a shoulder on a valve stem, this should be carefully filed off, and the valve heads scraped. A much worn stem will allow part of the exhaust gases to pass, but this is not a serious matter. A complete spare valve should always be carried, which can be used, if necessary, should a spindle break. It is very convenient to have interchangeable valves, but in overhauling, care should be taken that each valve is replaced upon the seat to which it has been ground.

On replacing the cylinders some difficulty may be found in entering the pistons, but with care and gentle persuasion the cylinder will go down on to its face. The nuts should then be run down and evenly tightened up all round, after making sure that the faces of the cylinder and its seat are clean, and that no one nut is tight before the remainder are nearly home. Irregular tightening of the nuts may result in a broken cylinder. The tappets should then be carefully adjusted, allowing a clearance equal to the thickness of a piece of stout brown paper between the tappet head and the valve stem.

The water circulation system and the ignition gear can then be replaced, but the pump requires inspection; as a steel pump spindle working in a gun-metal casing is very liable to pit, owing to galvanic action. Also the high speed at which a pump rotates tends to wear the spindle where it passes through the packing. A worn pump spindle should at once be renewed, as this is a most vital as well as a much forgotten part of a car's mechanism.

The cam gear wears very little, and if well hardened need cause no apprehension on the part of the motorist. If a hump forms on a cam, it may be ground carefully off, but generally speaking it is better not to touch it. The half-time gears, too, as a rule, wear well, and need no attention from the motorist beyond oiling.

The governor should be taken apart and freed from any gumminess. The governor fork is liable to much wear in some cars, and may require renewing, otherwise the engine will hunt. It should be noticed that when the governor is at rest, the throttle upon which it acts is fully open, and that this opening is not affected by excessive wear of the pins or other small gear. Conversely, when the governor is fully distended, the throttle should shut. A useful arrangement can be made in connection with the governor, viz., a foot throttle, which works in the reverse direction to the accelerator.

The Clutch should require but little attention, the chief point of wear being the fork, and in some cases the leather, where this material is used. However, most clutch work must be done in a workshop. A good clutch should run without attention for years, or with an occasional dressing of castor oil. This small attention is obviated in many modern cars by the employment of disc clutches which run in an oil bath.

Ignition systems are quite numerous in modern cars, and, except for such details as wiring and contacts, all repairs should be done by the makers of the various apparatus.

In the coil and accumulator system which has held the field for so long, great attention should be paid to the contacts, these should be kept clean and the platinum points in good trim and carefully adjusted, the usual precautions being taken to avoid leakage or faults in the wiring. Protection of all the parts from oil and dirt should be the first consideration, and if these precautions are taken, there should be no stoppages on the road for ignition troubles. Of course plugs sometimes fail, but good ones are always the cheapest and most satisfactory. Cracked porcelains should be watched for—or rather detected by the ear, as it is often impossible to *see* the flaw in a porcelain. Slight side pressure with the fingers will produce a grating sound if there is a fracture. If ordinary care is taken in driving to produce the proper explosive mixture, and there is no excessive lubrication, and the batteries are properly charged, there should be no trouble at all from sooty plugs.

The author has driven many thousands of miles without even inspecting the end of a plug—or adjusting a trembler. With reference to tremblers the blades are liable to fatigue, and if a spare one is carried, those attached to the coils can be given a rest in turn with advantage. Coils themselves are too delicate to be touched or repaired in any way except by thoroughly competent people. The same remark applies to magnetos, as the wiring of these electrical appliances is a specialty in itself.

As regards magnetos, now so generally in use and so entirely satisfactory in operation, if they do go wrong it is usually at a most inconvenient moment. Supplementing the previous remarks, therefore, it is advisable to have some duplicate system, even though it be an accumulator and single wound coil. This appliance will work admirably from a low tension make and break system, and can be connected in the ordinary way in parallel with the armature of the magneto to be switched on when required. The only drawback to a supplementary accumulator is that it is too frequently neglected. All accumulators should be kept properly charged whether in use or not. A small dynamo attached to the dashboard of a car more than repays the initial outlay, and the general behaviour of the engine is improved, particularly when running at a high speed.

Low tension magneto plugs require constant adjustment, the stationary pin wears or burns away rapidly and results in a failure to make contact with the moving arm. The small pins also require attention from time to time, and the plug packings round the moving arms must be kept in order, or loss of compression will result, particularly at low speeds. The high tension magneto is coming more into favour in modern cars, and it has the advantage of fewer moving parts. All small mechanisms are to be avoided, especially when arranged in an awkward and hot place, as they often lead to vexatious trouble upon the road. In these matters simplicity is the root of satisfaction, and it is often a mistake to assume that because there are more parts in one car than another that that car is better value for the money.

There is one part of a car which, in time of emergency especially, is more important than any other, and that is the steering gear. If by chance a car runs away, or is for a moment in a tight corner, it is upon the steering gear that the safety of the car, and sometimes the lives of the occupants, depends. Be sure, therefore, that all parts of the steering gear are in order, particularly the ball and socket joints. If this ball has to bear the weight of the steering rod, it is advisable to fit a spring to support the weight of the rod at this end. This spring will greatly reduce the wear upon both ball and socket and add to the safety of the car and its occupants. Too much attention cannot be given to the joints in the steering mechanism, both as regards lubrication and protection from mud and dust.

Small accumulations of these mixed with grease often hide serious defects, which are not detected until too late. If possible, cover the joints with leather protectors, and see that these covers are removed from time to time and fresh grease inserted. Also notice if the front wheels continue to run in line with the rear wheels—this can be tried with a string. Jack up the front axle and note if the backlash in the steering mechanism allows the front wheels to move an equal distance each side of the true line. If this is not the case, the cross rod between the steering arms of the front wheels must be shortened or lengthened accordingly, otherwise undue wear of the tyres will result. In conclusion the writer hopes that the real motorist will take interest in his cars as though they were the productions of his own brain and handiwork, as this is the only true means of obtaining really satisfactory non-stop runs free from roadside trouble and petty worries. A car well treated will be as good a servant as the best horse can be, and reasonable attention is all the car asks for. Always renew a part which shows signs of wear, and remember that an automobile is a beautiful and delicate machine and not simply a carriage driven by an unseen power under the bonnet.

APPENDIX.

It must be borne in mind that the bulk of the spirit usually employed at the present time comes largely from the Eastern oil fields.

This spirit differs considerably from the products of the Pennsylvanian fields, upon which calculations have been based in the past, owing to the presence of large proportions of hydrocarbons of the benzene (C_nH_{2n-6}), the naphthene ($C_nH_{2n-6}+H_6$), and other groups.

The following tables (Redwood) explain the reason why specific gravity has very little bearing upon the quality of the fuel :—

DISTILLATES FROM PENNSYLVANIAN PETROLEUM.

Name.	Formula.	Boiling-point.	Specific Gravity.
		Degs. Cent.	
Hexane (normal) -	C_6H_{14}	69	0.664
,, (iso) - -	,,	61	,,
Heptane (normal) -	C_7H_{16}	97·5	0.699
,, (iso) - -	,,	91	,,
Octane (normal) -	C_8H_{18}	125	0.703
,, (iso) - -	,,	118	,,
Nonane - - -	C_9H_{20}	136	0.741
Decane - - -	$C_{10}H_{22}$	158	0.757

NAPHTHENES FROM RUSSIAN PETROLEUM.

Formula.	Boiling-point.	Specific Gravity.
	Degs. Cent.	
C_6H_{12}	69	0.754
C_7H_{14}	95 to 98	0.742
C_8H_{16}	115 to 120	0.777
	122 to 124	0.783
C_9H_{18}	135 to 136	0.781

BENZENES. (Vivian B. Lewes.)

Formula.	Boiling-point.	Specific Gravity.
	Degs. Cent.	
C_6H_6	80	0.88
C_7H_8	110	0.87
C_8H_{10}	142	0.87
C_9H_{12}	170	0.85

Calorific Values.

1 British Thermal Unit (B.T.U.) is the quantity of heat required to raise 1 pound of water through 1 degree Fahr.

1 Calorie (Major) is the quantity of heat required to raise 1 kilogramme through 1 degree Cent.

Pure anthracite = 14,000 to 15,000 B.T.U. per lb.
Semi-anthracite, or Welsh coal = 13,500 to 15,500 " "
Bituminous coal = 11,500 to 15,000 " "
Coke = 11,000 to 12,000 " "

Pennsylvanian light petroleum = 18,000 to 22,000 B.T.U. per lb.
Russian light petroleum = 20,500 to 21,500 ,, ,,
Borneo light petroleum = 19,000 (approx.) ,, ,,
American petroleum spirit = 18,500 to 20,000 ,, ,,
Benzol = 18,500 ,, ,,
Coal gas = 500 to 600 B.T.U. per cubic foot.
Producer gas = 120 to 160 ,, ,, ,,

Latent Heat—Water = 966 B.T.U. per lb.
Hexane = 210 ,, ,,
0.700 sp. gr. Petrol = 250 to 288 ,, ,,
Benzol = 232 ,, ,,
Commercial alcohol = 520 ,, ,,

Useful Data.

1 millimetre = $\frac{1}{25}$ inch (approx.).
1 inch = 2.54 centimetres.
1 centimetre = 0.3937 inch.
1 foot = 0.3048 metre.
1 metre = 3.28 feet = 39.37 inches.
1 cubic foot = 0.0283 cubic metre = 6.24 gallons.
1 cubic metre = 35.32 cubic feet = 220.2 gallons.
1 gallon = 277 cubic inches = 0.1605 cubic foot = 4.54 litres.
,, = 4546 cubic centimetres.
1 litre = 0.2202 gallon = 0.03532 cubic foot.
,, = 0.2642 American gallon.
1 pound = 0.454 kilogramme.
1 kilogramme = 2.2 pounds.
1 cubic foot of water weighs 62.43 lbs.
1 cubic foot of air at 0° Cent. and 760 millimetres weighs 0.0809 lb.
1 cubic metre of air at 0° Cent. and 760 millimetres weighs 1.293 kilogramme.
1 kilogramme of air at 0° Cent. and 760 millimetres occupies 0.773 litre.
1 lb. of air at 0° Cent. and 760 millimetres occupies 1.24 cubic foot.
1 inch water column = 0.036 lb. per square inch.

1 degree Centigrade = $\frac{9}{5}$ degree Fahr.

Temperature in degrees Fahr. − 32 and × $\frac{5}{9}$ = temperature degrees Cent.

1 B.Th.U. = 0.252 kilo-calorie.

1 kilo-calorie = 3.9672 B.Th.U.

1 calorie per kilogramme = $\frac{9}{5}$ B.Th.U. per lb.

1 calorie per cubic metre = 0.1124 B.Th.U. per cubic foot.

1 metric horse-power = 75 kilogramme metres per second.

" " = 0.9863 British horse-power.

Fuel consumption of 1 kilogramme per metric horse-power hour = 2.235 lbs. per British horse-power hour.

1 kilogramme per square centimetre = 14.22 lbs. per square inch.

1 lb. per square inch = 0.07 kilogramme per square centimetre.

Rear Axle
Storage Battery
Magneto.

INDEX.

Printed at THE DARIEN PRESS, *Edinburgh.*

gckw

750 net w

$2^{\underline{w}}$