THE WORKING AND MANAGEMENT OF STEAM BOILERS AND ENGINES

FREDERICK COLYER

TREATISE

ON THE

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SHAFTING, GEAR, AND MACHINERY.

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BY

FREDERICK COLYER, M. INST. C.E., M. INST. M.E.,

CIVIL ENGINEER;

AUTHOR OF 'BREWERIES AND MALTINGS, THEIR ARRANGEMENT AND CONSTRUCTION, ETC.';
'HYDRAULIC, STEAM, AND HAND-POWER LIFTING AND PRESSING MACHINERY';
'PUMPS AND PUMPING'; 'MODERN STEAM ENGINES';
'CONSTRUCTION OF GAS WORKS'; 'ENGINEERING OF PUBLIC INSTITUTIONS';
'WATER SUPPLY AND DRAINAGE.'

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PREFACE TO SECOND EDITION.

THE present edition has been carefully revised and partly rewritten; much new matter has been added, including a chapter on Shafting and Driving Gear, to make the book more complete, with the hope that it will also be still more useful to those for whom it was originally written. Very technical matter has been as far as possible omitted.

I should like it to be understood that in cases where names of manufacturers are mentioned as well fitted to carry out certain work, it has been done solely for the guidance and convenience of the reader, and not with the intention of unduly bringing forward such firms to the detriment of others who may be equally able to execute such work.

I hope I have succeeded in making the book even more acceptable to my readers than the former edition. Trusting to their lenient consideration for all defects, I now leave the work in their hands.

FREDERICK COLYER,
M. INST. C.E., M. INST. M.E.,
Civil Engineer.

18, GREAT GEORGE STREET,
WESTMINSTER, S.W.
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PREFACE TO FIRST EDITION.

I HAVE been induced to write this work for the purpose of providing a small treatise giving an outline of the principal kinds of engines and boilers in general use, to indicate the most suitable forms for particular purposes, and to give simple rules as to their working and management. I do not think that any work has yet been written that is of much service to the proprietors and users of steam engines and boilers, for whom this work is specially intended. The design of the book is to convey leading instructions and simple rules as to the working and management of steam boilers and engines, in a form easy to understand; it is hoped that the work may be acceptable to those for whom it is principally intended, as well as for any one who takes an interest in such matters.

The large number of engines and boilers in use in this country, and the small knowledge possessed by many proprietors of such apparatus as to the proper and economical way to work them, will be, I hope, a sufficient apology for this attempt to supply a want many have expressed for a book of this kind.

With all its faults and shortcomings, I leave it to the lenient consideration of my readers.

FREDERICK COLYER,
M. INST. C.E., M. INST. M.E.,
Civil Engineer.

18, GREAT GEORGE STREET,
WESTMINSTER, S.W.
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ON THE

WORKING AND MANAGEMENT

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STEAM BOILERS AND ENGINES,

SHAFTING, GEAR, AND MACHINERY.

CHAPTER I.

INTRODUCTION.

THE proper and economical working and management of steam boilers and engines is a subject worthy of careful consideration, seeing that the various mills and manufactories in the country usually derive the motive power for their machines from this apparatus. The subject does not appear hitherto to have had the attention it deserves. The object of this work is to give an idea to managers and proprietors of such places, as to the most suitable kind of engine and boiler for their purposes, and to supply them with suggestions as to the best system of management. The selection of the best kind of engine suitable for a mill or manufactory is often a matter of some difficulty; to meet this want a general outline of each class in general use is given, to help the purchaser to form a right judgment in the matter. It is not intended to enter into much detail as to the construction of boilers and engines, it being assumed that most people who read the book are fairly conversant with such matters. In many factories a large loss annually takes place from the careless management of the motive power; it too often happens that the working is left in the hands of ignorant men, with the result of great waste in fuel, and too often in the occurrence of serious accidents. The author ventures to recommend all users and proprietors of steam boilers and engines to make themselves acquainted with the general construction and working of the machines by which motive power is given to their mills, and also that they should use more discretion in the selection of men to whom are intrusted the care and working of apparatus so fraught with danger and possible heavy loss, when not skilfully managed. Added to which, a careless stoker or engine driver will cause heavy loss in the extra quantity of coal used beyond the amount really required when the boilers are properly worked. The first subject treated is "Boilers, their Fittings and Appliances," with proposals for their proper working and economical management. An outline of the different classes of boilers is given, also an idea of the most suitable kinds adapted for particular purposes. Engines are then treated: a short description of the forms or classes generally used is given, and rules for working, speed, consumption of steam, &c. Boiler and engine house construction is also treated, together with boiler (brickwork) settings, and the foundations for engines. Technicalities have been avoided as much as possible, in order to make the work more useful to those who are not engineers by training, and to express, in plain language, rules and ideas for their guidance. The subject of engines and boilers is too large to treat in detail here; any one wanting further information is referred to the author's book upon 'Modern Steam Engines and Boilers' (E. & F. N. Spon, London), in which will be found details of construction of all descriptions, both for land, locomotive, and marine purposes.

CHAPTER II.

BOILERS.

THERE are two principal classes of boilers in general use for land engines, viz. vertical and horizontal; the former are usually of the tubular kind, the latter are made in several forms, viz. "Cylindrical," "Cornish," "Lancashire," "Multitubular," "Return flue" and "Water tube." A short description of each kind will be given, to enable the reader to form an idea of the respective merits of each class and their adaptability for particular kinds of work and under special circumstances. It will also enable the reader to understand more clearly the rules laid down for working, &c. The Cylindrical, Cornish, and Lancashire kinds require setting in brickwork; the Multitubular do not require any setting. There are many cases where a brickwork setting could not be used, partly on account of the limited space at command, and also in places where the extra dead weight could not be permitted; multitubular boilers on the locomotive plan are the most suitable in such a case; the boiler rests upon iron cradles, the exterior being covered with felt or non-conducting composition.

Water tube boilers are set in brickwork in much the same way as the Cornish and Lancashire types.

They, however, possess this advantage over any other boiler—that they can be taken into a building in parts, and through much smaller spaces than required for the admission of any other kind.

Before entering on a detailed description of the various types of boilers and their construction, it is recommended that only the best class of workmanship and material should be accepted. This will be found to be true economy in the end, not only as far as the wear is concerned, but also, owing to their superior design, better working results will be obtained. It is also recommended that great care should be used in intrusting the brickwork setting to firms who have great experience in this kind of work; the faulty setting of a boiler affects very much the consumption of fuel as well as the wear of the plates, &c. When a special kind of fuel, such as hard wood, is to be burned, the furnaces must be constructed for the purpose, both with regard to the area of the furnace bars, and the air spaces required between them.

Vertical Boilers

May be divided into three classes, viz. cross tube, multitubular, Field's tube and other patents. Each of these will generate steam rapidly; for simplicity the multitubular and cross or inclined tube are to be recommended. Vertical boilers are only suitable where the floor space is limited; and in cases where temporary steam power is required they can be placed upon a stone foundation resting upon concrete. In some instances the boilers can be fixed upon an iron frame or truck running on wheels; they can thus be easily taken to the required spot in a short time and can be rapidly made ready for work. The smoke shaft or chimney is made of wrought iron plates put together in short lengths; and where the engine is near the boiler the blast pipe should be put into the chimney to increase the draught. It is essential that the boiler should rest upon a dry foundation and be protected from the weather. For temporary pumping purposes these boilers are very suitable; the space occupied is small, and as they do not require any brick-work setting their weight is much less than most other boilers.

Cross tube Boilers are suitable for rough work, especially where unskilled labour is employed to work them; they do not require much attention from the stoker, and are not so liable to leak as some of the other kinds. In this class of boiler there is an internal fire-box of the usual description, and on the top of this is riveted an internal tube or flue with several cross tubes passing through it; the water in the boiler passes through these tubes, and by this means steam is generated quickly. These boilers are specially suitable for portable steam cranes, pile-driving machines, mortar mills, and temporary work either indoors or out.

The fire-box and tubes should be made of Low Moor iron, except when the boiler is made of steel. The fittings required are—3-inch safety valve, steam valve, $1\frac{1}{2}$-inch feed valve and back-pressure valve, 2-inch blow-off cock, $2\frac{5}{8}$-inch gauge glasses, Bourdon's steam gauge, Gifford's injector and a feed tank. In some cases a steam feed pump may be preferred.

The boiler should be covered with non-conducting composition and when much exposed to the atmosphere should also be covered with sheet iron or wood lagging.

Coke may be used with advantage in these boilers, or Welsh coal where it can be obtained at a moderate price. The working pressure is usually 45 to 50 lb. per square inch—this, of course, depends upon the work to be done. The feed water should be heated when the exhaust steam from an engine is available.

Multitubular Boilers are made in much the same manner as a locomotive boiler, with an internal fire-box and tube plate; a large number of small tubes are riveted to the top of the fire-box at one end and to the tube plate near the top of the boiler, which also forms the bottom of the smoke-box. The heat from the fire passes through these small tubes, which present a large heating surface to the water in the boiler surrounding the tubes, thus causing rapid circulation and generation of steam. The steam space in these boilers is of necessity rather small, and priming sometimes takes place unless the boiler has careful attention; it is sometimes caused by using dirty water, or by the presence of grease or tallow in it.

The construction of the boiler as to the shell and other parts is the same as the cross tube kind; the fittings may also be the same. Multitubular boilers are not suitable when the water is of inferior quality or containing salt or other deleterious deposit; in such cases the cross tube kind are to be preferred. Boilers of the class under consideration are well adapted for working under pressures of 70 to 90 lb. per square inch; in this case the thickness of plates has to be adjusted. Greater care is required in moving boilers of this class to avoid injury to the joints of the tubes at the tube plates. They require more careful attention from the stoker, because they generate steam more rapidly, and also because the steam space is usually rather less than in the cross tube class. It is also necessary to examine them more frequently to ensure that incrustation does not take place on the tubes. In all vertical boilers, the seams should be as few as possible, and where extra cost is not an object lap joints should be avoided, and butt joints with cover plates used instead. These boilers may be made of steel plates; they are much lighter as to weight, and do not cost much more than when made of iron.

Field tube Boilers are made with a fire-box as before; the top plate is drilled with a number of holes about 2 inches in diameter, and in these holes are suspended short tubes, closed at the lower ends and open at the top, which are in communication with the water in the boiler. In these tubes internal tubes are placed; these are open at both ends, and at the top are made funnel shape and have wings attached to suspend them in the external tubes; the cold water passes into the external tubes, and when heated it passes up the centre tubes; very rapid circulation is thus produced. Boilers of this kind are often adopted for steam fire-engines, and in cases where boilers are used in the portable form. They are not so suitable for chalky water, and where there is silty deposit of any kind. This class of boiler has given much satisfaction in many cases, and is useful when it is required to generate steam rapidly; they of necessity require much more attention than the boilers before described. The general construction and the valve and other fittings may be the same as before described; the same remarks also apply as to fuel and feed water.

There are several other kinds of patent boilers with inclined tubes, &c.; they are not, however, generally so suitable for factory purposes, and therefore need not be specially described. As a rule, unless skilled labour is employed, vertical boilers that generate steam very rapidly are not to be recommended for ordinary use; the steam space in all cases is small as compared to other classes of boilers. Where space is available for placing a horizontal boiler, it is not advisable to adopt the vertical kind—they are not so economical in working as regards the fuel used, and require much more attention. Proprietors of mills requiring vertical boilers are strongly recommended to order them of ample size—it is true economy, as steam can be kept up more easily and at less cost for fuel than for smaller boilers.

All the boilers above described have the smoke-shaft attached directly to the top of the smoke-box; it is usually made 9 or 10 inches in diameter, of wrought iron, in about 8 feet lengths, each length being flanged to admit of making it of sufficient height to obtain the requisite draught. The draught of the boiler as before named is increased by carrying the exhaust pipe from the engine into it; this, however, is only useful in rather short funnels. Each length of smoke pipe should be well jointed, and when the pipes are of any height above 10 feet they should be properly stayed with iron rods.

Horizontal Boilers.

Cylindrical.—These are a very useful kind of boiler; they are made with a cylindrical shell or casing, and have the ends riveted on, which are either made cup-shape in one piece or hemi-spherical. The shells are made in as large plates as possible, and each of the ends solid flanged; a steam chest is riveted to the top of the shell of the boiler; manhole and mudhole doors are also provided. The furnace is placed *under* the shell. The seams or laps of the plates of the boiler must be placed *away* from the front of the furnace to prevent the flames injuring the joints; it is the custom to make the front plate over the fire of sufficient length to go *over* the bridge of the furnace. The area of the furnace bars for this kind of boiler must not be less than 1 square foot per nominal horse-power, and in cases where much refuse is required to be burned it must be made rather larger.

The fittings of the boiler should be: Two glass water gauges, to show the height of the water in the boiler; the reason for fixing two of these water gauges is to ensure that the true water-level is shown, in case the passages of one set should get stopped from any cause. Two gauge-cocks should be provided, one being fixed at the steam space and one at the low water-level. A safety valve should be fixed on the top of the steam chest, for the purpose of giving relief to the steam in the boiler when it rises above the maximum working pressure. A steam shut-off valve should also be fixed on the steam chest, to regulate the supply of steam from the boiler and to shut it off when required. A feed valve and supply pipe should be attached at the front of the boiler, for the purpose of supplying the feed water. A blow-off cock should be fixed at the bottom of the boiler at the front, to blow out the steam and water at intervals and when it is thrown out of action. A float and alarm whistle should be placed on top of the shell to indicate the level of water in the boiler, and to give an alarm in case it falls too low. A steam gauge must be fixed at the front of the boiler to show the internal pressure. An injector should be fixed at the front for supplying the feed water, and a tank placed on top of the brickwork setting to supply the same. This tank should be fitted with a self-acting ball valve; it should *always* be placed *above* the injector. In most instances it is preferable to have a direct-acting steam feed pump—they are very useful machines, and not liable to get out of order; the amount of steam used by the best kind of pumps is small. The top of the boiler exposed above the brickwork setting should be covered with non-conducting composition; the steam pipe should also be covered. These boilers are the most simple to use, especially abroad, but where the cost of fuel is great they are not so economical as the tubular class. They are absolutely safe, and therefore specially useful when unskilled labour has to be employed. The boiler may be made of iron or steel plates; in the former case a Low Moor iron plate should be provided over the furnace, and be of sufficient length to go over the bridge placed at the end of the furnace bars.

These boilers have to be set in brickwork; the top, however, should be left open, and can be covered with non-conducting composition. In cases where refuse of any kind is to be burned the furnace must be made specially large. A pan of water should be placed under the furnace—this keeps the bars cool and increases the draught.

The damper of the main flue should be operated by a chain carried to the front of the boiler and placed in a convenient position. Where several boilers are to work into one chimney shaft dampers must be provided in the main flue between each. *The blow-off pipes* should be placed in a brickwork channel under the floor of the boiler house, and be carried to the drain or dry well provided for the purpose.

Cornish Boilers are constructed with an outer shell and one internal tube or flue passing through the whole length of the boiler; the end plates are made flat, and are attached to the shell and tube by L-iron rings, or they may be solid flanged and riveted direct to the shell plates; the tubes should be strengthened on the exterior at intervals with L-iron rings. The furnace is placed *within* the tube at the front end, the flame passing from the fire over the bridge at the end of the fire-bars, through the tube, and so out to the side flues and chimney shaft; the furnace bars are made in two lengths, supported on wrought-iron bars bolted to the internal tube of the boiler; a fire-door is fixed to the front plate. A steam chest is provided on top of the boiler as before; the hole in the shell at this place need not exceed 6 inches to 8 inches diameter; this is sufficient for steam to pass through, and prevents the shell plates at this part from being weakened by cutting a larger hole. The manhole should be placed at the back of the steam chest and near the end of the boiler; a ring should be riveted round the opening to give it strength, except in cases where a cast or wrought iron frame is riveted on to the shell, as this answers the same purpose. This is much the best plan; as the joint of the manhole cover is planed it can easily be taken off and re-jointed without risk of leakage. The steam pipes and connections of all kinds should be attached to cast-iron seats riveted to the boiler. These joints should be faced and the holes drilled; this allows the pipes to be easily and quickly removed in cases of emergency, and prevents injury to the plates of the boiler by leakage at the various points of attachment.

The fittings for a boiler of this kind will be the same as before described (p. 11). The size of the various fittings will, of course, depend upon the power of the boiler. This kind of boiler is not made in larger sizes than 5 feet 9 inches to 6 feet diameter; where larger power than this is required the Lancashire type or two-tube boilers should be used. The front of the boiler should have gusset stays, to connect the end plates with the shell.

Cornish boilers are a very favourite type, they are economical in working, and quite safe with an ordinarily intelligent stoker. They require setting in brickwork (this is described at p. 24); this work should always be done by specially skilled people, as upon the proper setting will much depend the economical working of the boiler, both as to fuel used and wear of the plates. The same remarks as before as to fuel, feed water, and other details, equally apply to this type of boiler.

Lancashire Boilers.—These boilers are made in the same way as the above, except that they have *two* internal tubes or flues ; the end plates are made flat and are attached to the shell and tubes in the same manner as before. A furnace is placed inside *each* tube, and furnace doors, fixed to the front plate, are provided to each. This class of boiler is used when the diameter exceeds 5 feet 9 inches to 6 feet.

The fittings and furnaces do not differ from those described for Cornish boilers. The diameter of these boilers should not exceed 7 feet 6 inches to 8 feet as a maximum, and the length about four to five times the diameter. The area of the fire-grate should be $\frac{3}{4}$ square foot per nominal horse-power, and the length of the bars, if it can be avoided, should not be more than 6 feet. The seams of the shells should be double riveted ; the front and end plates should each have four diagonal braces or gusset plates to connect them with the shell and tubes ; the internal tubes should have rings at intervals riveted to the exterior ; and all the laps, seams, or joints placed *away* from the furnace. The boiler should be set to drain at the front end at the blow-off cock, and be provided with proper mudhole doors for cleaning out. The steam chest is the same as for Cornish boilers; the Lancashire type is most economical in action. The furnaces, especially as to the air spaces between the bars, must be adapted to the particular kind of fuel to be used.

When two or more boilers are required, they should be connected together by a steam pipe, a shut-off valve being provided on the steam chest of each boiler, and also on the main pipe between each set or sets of boilers, to enable the steam to be shut off from any part when required. An expansion joint, made of copper, should be placed in the pipe between each boiler, to allow expansion in the boilers and pipes to take place without doing injury to the joints of the valves and pipe connections. In other details these boilers do not differ from the Cornish class.

Multitubular Boilers.—These are made upon the locomotive plan, with an external shell and an internal fire-box or tube at the front end. The tube is closed by a plate at the end of the furnace and in this plate a number of small tubes 1½ inch to 2 inches diameter pass through and are riveted; at the other end of the boiler another plate is riveted to the shell, and through this plate the back ends of the tubes pass and are riveted. The shell plates of the boiler are continued beyond this end tube plate forming the smoke-box, the end being closed by a plate which is provided with a hinged door to enable the small tubes to be cleaned out. The furnace bars are placed in the large tube at the front of the boiler; the flame passes over the bridge through the small tubes to the smoke-box, the water surrounds these tubes, and by the large heating surface they present, steam is rapidly generated. The flues to the shaft are usually constructed of wrought-iron plate, and may be carried some distance without injury to the draught. The fittings for the boilers do not differ from those described for the Cornish and Lancashire types.

The exterior of the boilers should be protected by felt and lagged either with wood or sheet iron, secured by wrought-iron bands, or they may be covered with non-conducting composition as before described.

Boilers of this class are very suitable where steam power is required on a quay or jetty, or when placed in vaults or on the upper floors of a building; they do not require any brickwork setting, they are very economical as to the consumption of fuel, generate steam quickly, and will last for many years when used with ordinary care. They rest on cast-iron cradles: these may either be placed direct on a stone floor or on timbers; in both cases a good sound bed under the stone must be obtained. When the soil is boggy piles may be driven under each place where the cradles have to rest, and a platform of timber placed on the top, and concrete and stone bases on this.

Boilers of this class may also be used for temporary purposes; they are quickly set to work, and, not requiring any foundation, can be also easily and rapidly removed when done with; in cases of this kind the smoke-funnel may be fixed direct to the top of the smoke-box. The pipes forming the funnel or shaft should not be in more than 8 feet to 9 feet lengths; they should have faced flange joints and be bolted together, and properly stayed with wrought-iron ends. This type of boiler, when required for pressures of 80 to 150 lb. per square inch, may be made with a fire-box end in the same form as a locomotive (railway) boiler—in this case the boiler should be made of Siemens-Martin steel. When made with a locomotive fire-box as described, this end of the boiler may rest direct on the foundation stone, and the other be supported on a cast-iron cradle resting upon the stone at that end. When this type of boiler is properly protected, it may be worked as economically as any other kind. This form is also used for portable boilers for temporary purposes; they are placed upon an iron frame on wheels, and can be run on the spot where required, and worked direct, without making any foundation. They are often used with engine combined, which is either placed on top or under the boiler; the advantage of this arrangement is that it is compact, it takes little room, and can easily be moved from place to place—added to this, it requires very little foundation and thus saves much expense.

Return Flue Boilers.—These boilers are not very generally used. The manufacturers claim for them some advantages, such as saving in room and increase in the heating surface; but in ordinary cases their use cannot be recommended. They are constructed on much the same plan as a marine boiler, the fire being placed either under the shells or inside the tubes; the heated air and flame pass to the back of the boiler, thence by an uptake through a number of smaller tubes to the front plate, thence to the side flues if set in brickwork, and by the main flue out to the shaft. The doors for cleaning the small tubes in this case are placed at the front of the boiler. In some instances a long cylindrical steam chest is attached to the top of the shell of the boiler by two saddle pipes; in other cases vertical steam chests of the ordinary kind are used. The smoke funnel may be attached direct to the top of the smoke box if desired; this, however, somewhat affects the economy of working as to the fuel, as some of the heating power is lost. In some cases the internal tubes give trouble and leak: this may possibly be due to the fact that the shell is held in the brickwork, and cannot readily expand and contract.

These return-flue boilers are made in several forms; the above type is most to be recommended when it is decided to adopt this class of boiler. The fittings and construction do not differ from the multitubular boilers already described. It must be borne in mind these boilers are not suitable when the water is not of good quality, especially when it is salt or contains much deposit. They require much care in working and should never be placed in the hands of unskilled attendants. The tubes must often be examined and cleaned out and kept free from soot, and the exterior of the tubes must also be kept perfectly free from scaly deposit; each time the boiler is thrown out of use—say once per month,—the exterior of the tubes must be carefully swept and scraped if necessary. If this is not very carefully attended to, the tubes will be burned out, and much inconvenience if not actual danger caused.

Water Tube Boilers.—There are several of this type of boiler; the principal in use are Babcock and Wilcox Patent, and Root's Patent. From the experience the author has had in the working of the two kinds of boilers, he recommends the Babcock and Wilcox type. This class of boiler possesses many advantages over Cornish, Lancashire, or multitubular boilers, on account of the facility and portability both for shipment abroad and for placing them in cellars and other confined places, and also on account of the comparatively small weight of the parts. The dead weight of the boiler when fixed is much less than the Cornish or Lancashire type. A much higher working pressure can be used with perfect safety; they generate steam rapidly, and are very economical as to the fuel used. The author has fixed these boilers over cellars on girders, and in other positions where it would not have been possible to get any other kind into the place. They are very easily worked, remain perfectly tight at the joints of the tubes, and are absolutely safe. No damage can be done in the event of a tube bursting—it simply puts out the fire. All parts of the boiler are made of steel, and the whole arrangements are designed to facilitate easy working. The author has sent them to parts of South America, where, owing to the weight of other kinds, it would have been impossible to have delivered them on to the required spot. Another advantage is, they can be built to suit the place they have to be fixed in ; and in contracted entrances to boiler rooms, large boilers can be passed through spaces 3 feet 6 inches in width, where it would be impossible to take ordinary boilers in one piece. The fittings, &c., described for other boilers apply equally to these.

These water-tube boilers are set in brickwork, and are so arranged that they are entirely supported independently of the setting ; in the event of any repairs being necessary they can be carried out without in any way interfering with the joints or plates of the boiler. They require no more attention than the Cornish or Lancashire type, and can be readily worked by unskilled people. The average evaporation of water, with good steam coal, is about $9\frac{1}{2}$ to 10 lb. of water per 1 lb. of coal. Hard wood can be used as fuel with much advantage—the furnace in this case has to be specially prepared. A uniform pressure of steam can be easily maintained with less trouble than an ordinary boiler.

General Observations.—There are several other kinds of boilers in occasional use; as, however, there are very few cases where one of those before described cannot be employed, it has not been thought necessary to describe them in detail. The general proportions of the various boilers are not treated of here, as it would be beyond the scope of the present work; any one requiring any further detailed information as to this is referred to the author's book upon 'Modern Steam Engines' (E. & F. N. Spon).

Too much stress cannot be laid upon the importance of the proper proportions and careful manufacture of boilers and their fittings; only manufacturers of the highest reputation should be entrusted with such work. It must be borne in mind that cheap and inferior work may not only prove a source of danger, but will be the dearer in the end, from the constant loss occasioned by the extra consumption of fuel that may be necessary to generate steam, and the frequent repairs that may also be required on account of faulty work and inferior design. Proprietors and users of boilers will best consult their own interests by careful attention to the above. From an experience of many years, the author has found that several large and well-known makers of boilers have never had an accident of a serious nature occur to their boilers, unless caused by *the culpable neglect of incompetent men* who had charge of them. He also believes that the accidents and explosions that only too often occur to boilers would be almost entirely prevented by only employing firms of the highest reputation, as recommended above. To carry out the design of the book, the author thinks he has given all the details that appear to be necessary. It is not intended to discuss the design and proportions of boilers: this should either be left to a professional adviser or to a well-qualified manufacturer of boilers.

CHAPTER III.

BRICKWORK SETTINGS FOR BOILERS.

CYLINDRICAL, Cornish, and Lancashire boilers, also return-flue boilers, require setting in brickwork. In the preparation of the bottom much care should be used to obtain a solid and dry foundation; an excavation should be made until good sound soil is found; on this should be laid a bed of concrete from 12 inches to 24 inches thick; the thickness of this will, of course, depend upon the nature of the soil. The brickwork foundation should be carried over the entire surface of the concrete, with proper footings, about four courses or 12 inches deep. The bottom of the flues for Cornish or Lancashire boilers should be kept as near the floor-line as possible, and means taken to ensure their being kept free from damp and water; the side flues should be of sufficient size to permit of periodical examination; for this purpose, at the front of the flues cast-iron doors and frames set in the brickwork should be provided; flue brushes should be passed through these doors to sweep out the flues, and lads should be sent in at certain periods to sweep and clean them thoroughly; the exterior of the shell plates of the boilers should also be cleansed and kept free from soot and dirt.

The souffite of the brickwork side flues should be 6 inches below the top of the internal tubes in the boiler in the case of Cornish and Lancashire boilers, and 6 inches below the water-line in cylindrical boilers. Boilers should never be set with a centre feather or wall : it is a dangerous plan, as in the case of any leakage occurring, the plates are sure to get corroded, and being covered by the brickwork, such defects cannot readily be discovered when the men are examining the interior of the flues and the outer shell of the boiler. Another very grave objection to the centre wall is that the plates, owing to the dead weight of the boiler resting at this point, are liable to become flattened and strained ; this action constantly going on leads to permanent injury to the seams or joints of the shell, thus causing leakages and corrosion, which is a very fruitful source of danger ; a leaky seam at one end of the boiler may cause injury for some distance on the bottom plates in positions where it is difficult to discover them.

The best plan to set boilers is on two side fire lumps or walls, with side flues and a split draught into a bottom flue ; all the flues should be lined with fire-bricks 4½ inches thick. The exterior brickwork outside the flues should not be less than 14 inches or 1½ bricks; the front of the boiler should be built in blue (or black) bricks; the side walls should be carried about 14 inches above the top of the flues, and the brickwork covered with 3-inch York stone paving. The damper should work in a cast-iron slide and frame, and be connected to a chain passing over pulleys to the front of the boiler; a counter-balance weight placed in a convenient position is attached at this end of the chain. At the front of the brickwork setting a cast or wrought-iron foot-plate about 4 feet wide should be provided, and an open brickwork channel formed under the same for the blow-off and other pipes to pass through. A cast-iron door and frame should be provided at the blow-off cock; the plug of the cock should stand up, and be worked with a box spanner. The boiler setting should stand *quite independent* of the walls of the house; a space of at least 3 inches should be left between them to permit of expansion of the brickwork setting without doing any injury to the side walls: this is a most essential matter and should receive careful attention.

Setting of Return Flue Boilers.—This is on much the same plan as those described above. The fire is usually placed under the shell; the flame passes into a lower flue beyond the bridge to the end of the boiler, it then passes through the small internal tubes inside the shell to the front smoke-box; the draught is then split, and the heat passes into side flues to the shaft; the action may be reversed, or the side flues may be dispensed with. As before stated, this sort of boiler is seldom used, though there may be some circumstances where it may be desirable. In some cases these boilers are not set in brickwork, and are used like a marine boiler, the heated air only passing through the internal tubes to the smoke-box in the front of the boiler, and thence to the chimney. The boilers when not set in brickwork are covered with non-conducting composition, and are sometimes lagged on the outside with wood staves, secured by iron bands. The other details as to foundations are the same as for Cornish and Lancashire boilers.

The Materials used for the foundations should be as follows : The concrete should be made with Portland cement. The brickwork of the foundation and side walls should be built in mortar, with best stock bricks; the front may either be faced with picked bricks, white glazed or blue bricks; the corners of the settings should be formed with bull-nosed blue bricks. All the interior of the flues should be lined with best fire-bricks 4½ inches thick, when the cost of delivery does not prohibit their use. Stourbidge bricks are to be preferred ; they should be set in fire-clay. The top of the brickwork of side flues should be covered with York stone, say 2½ inches to 3 inches thick, tooled on the top and edges, and the bottom fair hacked. In the flues great care should be taken to avoid sharp corners or dips where it is possible to do so. All corners must be rounded, and where curves are used they must be easy. The flues must be kept absolutely dry, and easy means of access should be provided for examination and cleaning. The entry of the main flue from the boiler into the shaft must be carefully made: it must be of ample area and absolutely air-tight at this point.

BOILER SHAFT.

The *Shaft* need not be placed close to the boiler; if more convenient it may be put some distance away; the flues leading to it must be kept dry and air-tight. The height of the shaft from the ground line and the area at the top will depend upon the number and size of the boilers, and on other local circumstances; a soot-door should be provided at the bottom, to clean out when required. Several boilers may be taken into one shaft without any detriment to the draught; the shut-off dampers in the main flue must be closely fitted in this case, and made as air-tight as possible.

The interior of the flues and also the shaft for at least 15 feet high should be lined with fire-bricks; these bricks must *not* be bonded into the shaft, but left clear of it. The main flues, wherever possible, should be kept *above* the floor-line, in order to avoid any water or damp. The size of the flue will depend upon the number of boilers. Provision must be made for readily cleansing the flues, and also the bottom of the shaft.

For small boilers the shaft may sometimes be constructed of boiler-plate iron; it should be stayed by three tie-rods attached to a band near the top, and to any suitable place near the bottom, in case of heavy winds; this will keep the shaft in proper position. An air-tight soot-door should be provided at the bottom to give access for cleaning. The thickness of the plates should be $\frac{3}{16}$ inch to $\frac{1}{4}$ inch, and made with either lap or butt joints. In most cases the tube should be flanged, jointed at every 8 feet or 9 feet, and bolted together ; the joints must be made perfectly tight, to prevent any leakage of air into the shaft. A pocket to take surplus soot should be provided at the bottom, below the entrance of the flue from the boiler.

CHAPTER IV.

BOILER HOUSES AND WORKING OF BOILERS.

BOILER houses should be made of fair dimensions; the height should be about 12 feet to 14 feet from the floor-line to the wall-plate; the thickness of the walls may be 14 inches or $1\frac{1}{2}$ bricks. Ample ventilation should be provided, but strong draughts of air at the boiler front should be prevented wherever possible. No part of the boiler should be exposed to the weather; it is an error to leave the front or any part of the house open; not only is much loss of fuel caused by this, but injury is also done to the boiler plates by streams of cold air passing into the furnaces. Good light should be provided, and the windows made to swing; in large houses a lantern light may be constructed in the roof; part of the sashes in this case should be hung on pivots and be operated by simultaneous opening gear, worked from the floor of the house. The roof framing may be of wood or iron, close-boarded, felted, and covered with slates. The paving or floor of the house may either be laid with York stone or Stuart's patent granolithic pavement. Iron plates about 4 feet wide must be laid down in the front of the boilers, to allow the fires to be drawn without doing any injury to the floor. As a rule, stone will crack when heated coals or ashes are drawn on to it, and especially when quenched by water. In some instances it may be cheaper to lay the floor with hard paving bricks set in cement.

A coal bunker should be provided to contain the fuel ; this may be made of wrought-iron plates with sliding doors at the bottom to take out the coal as required. In some cases coal-trucks holding about 10 cwt., running on wheels, are found convenient ; they are provided with a shoot at the end or sides,—this is fitted with a sliding door. When there is space outside the house, the coal bunker may be constructed in brickwork, with a hole or holes at the bottom of the wall, fitted with sliding doors ; a large stock of coal may by this means be stored, and all inconvenience from dirt in the house avoided when delivering the coal. Allow 42 cubic feet per ton of coal stored, and allow for trimming.

The space for stoking in front of the boiler should be 8 feet in the clear. The feed apparatus *should be placed in the boiler house*, so that the stoker may not have to leave the house when it is necessary to immediately start the pump, on account of the level of the water in the boiler being too low. Whenever possible, the boiler house should be separated from the engine house, but a door of communication may be made between the two houses. That must not, however, be done in the case of gasworks, as the engine room contains the gas exhausters, and, in case of any leakage, the furnaces of the boilers might cause an explosion of gas.

The boiler house should be supplied with the following fittings :—

A set of spanners to take all the nuts; these should be placed on a rack on a board which should be fixed to the walls of the house. Box spanners should also be provided; these should be made with T heads. A complete set or sets of stoking tools, viz. two shovels, a rake, a slice, and a pricker; also a water hose, fitted with a union and cock, for quenching the fire when necessary. It is also convenient in some cases to fit up a vice and bench to do small repairs.

WORKING OF BOILERS.

The management and working of steam boilers, and the rules to be observed to prevent accidents, are a most important consideration; the want of a proper knowledge of such matters has too often led, as before stated, to serious accidents, causing loss of life, much suffering, and heavy losses to the proprietors. The following rules are given, the close observance of which will save proprietors of boilers much trouble, anxiety, and possible heavy loss :—

No men should be employed to look after a boil unless they have been properly instructed, and possess the requisite knowledge. It too often happens that a boiler is placed in the hands of men who are quite unfitted for the work, and who have had no previous experience; it may then become a very dangerous apparatus. It is to be hoped the Legislature will some day *make it obligatory on all boiler users and owners to employ only properly qualified men for the purpose*, and that boilers will be worked under State or municipal supervision. The author believes if this plan be carried out, accidents of a serious nature will be of rare occurrence, if not altogether prevented.

Having in former chapters given an outline of the general construction of boilers and the manner of setting them, the next important consideration is the water supply, and the fuel to be used; the best plan of stoking and the management of the fires is also very important. These matters will now be treated.

Water Supply.—Water for boilers should be obtained as pure as possible; river water, when clean and free from silty deposit, is very suitable; a hard water, especially from the chalk, is, as a rule, the most unsuitable; water containing sulphur, or ammonia, or any tarry matter, should never be used. A cast-iron tank containing sufficient for at least two days' supply should be provided, and fixed at a sufficient height to command the top of the boilers; this tank wherever possible should be placed under cover. Where the local water is very hard, it may be worth attention to soften it by the

Porter-Clark process; in the case of several boilers this will pay, as much corrosion is prevented, and the boilers do not require cleaning out so often —added to which the wear of the plates is much lessened.

The feed-water should be regularly supplied to the boiler; the water must not be allowed to fall to the minimum or *danger* level; if the water is supplied by injectors, care should be taken to see that they are in proper working order. This apparatus has been so much improved in late years, and is so simple to work, that with the most ordinary attention it is not liable to get out of order. A small feed-tank, from which the water supply is taken, should be placed on the top of the brickwork of the boiler; the main tank of the works should feed this by means of a self-acting ball-valve; care should be taken to keep the tank covered, and the water perfectly clean. The overflow from the injector should always deliver into an *open* funnel; if this is carefully watched when using the injector, no error or accident can take place. The feed-water should pass into the boiler *at about the water level* by means of a perforated tube running the whole length of the boiler; the feed-valve should be placed on the front plate and convenient to the man's hand; the valve should not be attached to the screw spindle, but be free to rise and fall on its seat, so as to prevent any of the water from the boiler running back to the pump in case of any break or stoppage in the pump or the pipes; in most cases a back-pressure valve is also added to act in case the valves stick.

Feed-pumps.—When water is supplied by a force-pump, direct acting or otherwise, the valves must be carefully looked to; pet-cocks are fitted to the pumps, by the opening of which the stoker can tell if the pump is working properly. When the pet-cock is opened, if no water passes through it, the valves may be stuck; in this case the stoker must try to release them by giving the valve chamber a smart tap with a hammer or mallet; the valves should then drop into their seats. Should they not at once do so, take off the bonnets of the valve-box and lift out the valves; a stick or some dirt may be the cause of the obstruction, and can thus be easily removed. If the level of the water in the boiler is low at such a time, the generation of steam must be stopped, the damper closed, and the fire-door opened. Should no defect be found at the valves, examine the plunger of the pump, to see if it is drawing air at the gland, and if so the gland must be screwed up to compress the packing. A back-pressure valve, as before named, is usually fitted in the delivery pipe to the boiler. The pipes must be carefully examined at intervals, to make sure no deposit has taken place in the inside, and the passage of water thus obstructed; this more particularly applies in cases where the water contains lime or other calcareous deposit. It is always advisable to have the feed apparatus in *duplicate* in every boiler house—either two injectors, or one injector and one feed-pump. Both the injector and the feed-pump should be of ample size, according to the power of the boiler.

Steam Pumps.—Since the introduction of direct-acting steam pumps, some years ago, they have been so much improved, and are now so moderate in price, that no boiler house should be without them. One advantage in favour of the steam pump is that it will draw water at about 25 feet below the suction valve, and at a *higher temperature* than is possible with the injector. The pressure of steam required to work the pump is not more than 20 lb. per square inch—the author has used steam as low as 15 lb. per square inch. The pumps can be worked from a few strokes to 60 or 70 per minute; a higher speed than this is not advisable, although in some instances it may be unavoidable; a certain amount of slip or loss of water through the valves must be allowed for in this case.

Water Heater.—The feed-water should be passed through this apparatus. It consists of a cast or wrought-iron cylinder having a number of small tubes inside it; the tubes may be made of wrought iron or copper; the exhaust steam from the engine passes through these internal tubes, and thus heats the water in the cylinder; or the action may be reversed, and the steam let into the cylinder and the water run through the tubes. Water may be used with the pumps at 120° of heat, and at even a higher temperature; but with the injector it should not be more than 100° to 110°. The size of the heater will of course depend upon the size of the boiler.

The Level of the Water in the Boiler must never in any case be less than 6 inches *above* the internal flues or tubes in the case of Cornish or Lancashire boilers; and in the case of cylindrical boilers not less than 6 inches above the top of the side brick-work flues; the water-line in multitubular boilers should not be less at any time than 6 inches to 7 inches above the top of the internal tubes.

The Glass Water-Gauges should be opened at frequent intervals to ascertain the level of water inside the boiler; the glass tubes should be opaque at the back, and be kept perfectly clean; the size of the cocks and tubes should be ample—the cocks should be the packed gland kind. As a rule, two of these water-gauges should be fitted to a boiler; in case of the glass tube breaking or stopping up in one, the other one is available, and will always indicate truly the actual level of the water inside the boiler. After one of the cocks of one set of gauges has been opened, try the other one, to make sure the level of the water which is indicated is the true one.

The Gauge-Cocks should also be opened frequently; the upper cock should show *steam,* and the lower cock *water*; *if water does not come out of this lower cock when opened, there is danger*—the water is too low, and an accident will take place if proper means are not taken to avoid it. In such a case, look immediately to the pump and injector if at work, and learn the cause of their not acting; should no water show in the glass or at the lower gauge-cock, immediately close the damper and open the fire door; *do not in any case put on the pump or the injector*; the blow-off cock may be opened and the fire drawn. Under all ordinary circumstances, when these rules are attended to, no accident will take place; such a state of affairs cannot at any rate arise unless there has been great neglect on the part of the stoker. The man in charge should carefully watch the level of the water in the boiler, and attend to any defect before the danger point above indicated is arrived at. As this is a most important matter, too great stress cannot be laid upon the necessity of diligent and intelligent care upon the part of the attendant, especially in all matters relating to the feed-water supply.

Fuel and Stoking.—The next most essential matter in connection with the working of boilers is the supply of fuel, and the manner of keeping up the fires. The best kind of fuel is clean screened small coal about the size of a pigeon's egg, usually called "nuts"; "slack" or coal dust is not economical to use, partly because it is mixed with rubbish, and also from the tendency to flare, and consequent loss of heat up the chimney—added to this, much more smoke is caused, which is a serious thing, especially in the London district, where the Smoke Act is in operation. In getting up steam in the morning, the coal that has been banked up on the dead-plate the night before should be pushed forward and spread in a thin layer of even thickness on the bars, and a small quantity of fresh coal placed on the top ; as the fire gets hot, more fresh coal should be placed on the dead-plate, and gradually pushed into the furnace ; by this means the green coal will be coked before it gets to the bridge at the back of the furnace. When the fire is made up, the red coals should be pushed to the back part of the bars, and fresh coal put on the dead-plate. When boiler fires are supplied with coal in this way, no smoke should be made. It must be borne in mind the object is to *prevent* smoke, *not to attempt to consume it* after it is made. If the furnace is fitted with rocking bars, they should be worked once or twice per hour to break up the clinkers, and to mix up the fire. Coke may be used as fuel, but it is not as a rule so economical as coal ; the two kinds of fuel should *never* be used together. Coal should be wetted before use ; a water pipe and hose in the boiler house is very convenient for this purpose ; it can also be used for quenching the fires when drawn. Good Newcastle coal is about the best to use in London; in country districts the nearest coal available must of necessity be used. It is not economical in any case to use very large coal; when too large, it should always be broken into moderate-sized pieces—this is essential for even and steady firing.

Welsh coal is sometimes used; it is almost smokeless, but is more expensive than other kinds; in some districts the high price, on account of the rates of carriage, entirely prohibits its use.

The air space through the fire-bars must be of sufficient area to suit the particular kind of coal; the hard and common kinds require a larger supply of air. The bars in all cases should be made rather narrow, and the air spaces close together; they are made in two lengths, and, as a rule, the total length of the furnace bars must be not more than 6 feet from the dead-plate to the bridge. Room must be left at each end of the bars to allow them to expand as they get heated; room for expansion must also be left across the bars. The fuel should be supplied not only *regularly* but *evenly;* the thinner the fire is the better. Keep the thickness of the fire at all times as equal as possible, and free from holes or bare spaces upon the bars; by opening the fire-doors at intervals this defect can be seen, and should be at once remedied.

Smoke Furnaces.—There are many appliances for the prevention of smoke in boiler furnaces; some are very effective in action. The object sought to be obtained in all is—the slow, regular, and perfect combustion of the coal; by this means all the gases are burnt in the furnace before the coal reaches the bridge; heated vapour in this case only passes to the flues, and by this means smoking at the top of the shaft is prevented. It is needless here to describe any of the numerous apparatus for this purpose; it may, however, be noted that the most successful kinds for hand-power or automatic working are: Wright's, Clarke's, and Martin's; and those driven by power: Juckes', Vickers', Procter's, Bennis's, and Smith's; those driven by steam power, as a rule, are only suitable for large boilers. They all effect much saving in coal, the commoner kinds of coal generating steam as well as the best kinds; a large saving in cost is thus effected. Furnaces of this kind of necessity require very careful attention; like most other things, they fail with careless and incompetent men. When well made they wear well, and do not cost much for repairs; the power required to drive them is small.

Finally, it must be remembered that a careless, ignorant, and incompetent stoker can increase the consumption of coal 30 to 40 per cent. by bad firing. No smoke should be emitted from the chimney when the stoking is performed in a careful, regular, and proper manner.

CHAPTER V.

FITTINGS OF BOILERS AND METHOD OF WORKING.

ALL well-made boilers are supplied with fittings as described at page 11, the most important of which are the *safety valves*. Particular attention is directed to these ; a large number of the accidents that occur to boilers have been traced to indifferent safety valves, or the neglect and careless use of them. The valves should be weighted to the maximum working pressure when the weight is in the end notch of the lever, and the lever should be graduated at spaces to give 10 lb. per square inch variation ; *under no circumstances should the valves be overweighted.* The valves should be kept clean ; if possible, they should be taken out of their seats once per week and cleaned, making sure that all corrosion and dirt is removed ; the pins and joints of the lever, &c., must also be examined and well oiled to ensure their working easily. If ordinary care is taken, no danger from over-pressure in the boiler can arise. The safety valves should always be made double—that is, two valves and seats should be fitted to one pedestal, to ensure that one valve will act, should the other stick from any cause ; the valves should have very free area.

The levers should never be lifted by the stoker; *it is attended with danger*. No one coming into the boiler house should on any pretence be allowed to touch the valves or levers, or any part of the boiler fittings. Lock-up safety valves are sometimes provided; they are weighted a little above the maximum working pressure, and will blow off if this is exceeded. A float and alarm whistle may form part of the safety-valve box; the height of the float indicator shows the level of the water inside the boiler, and the whistle gives an alarm when the point of danger is near. Directly the whistle begins to blow, the fire must be slaked, the furnace door opened, and the damper closed; the feed-water must *not* be put on if the water level is too near *danger* point.

The Feed-valve, the glass water-gauges, and the gauge-cocks and their use have all been described under the head of "Feed-water." The ways or passages of the cocks and pipes must be kept clean and free from deposit or any obstruction; the glasses must be kept perfectly clean and bright, and the cocks clean and tight at the gland packings.

The Blow-off Valve should be opened once or twice per day when the water is hard and likely to form a deposit; it need only be opened for a few seconds each time; this will prevent the scale from settling on the plates, and help to keep the inside of the boiler clean; the pipes leading from the boiler to the blow-off cock, and also the discharge pipes from the same, must be kept free from any dirt or deposit. If the blow-off cock is not used at least once per day, it is often found that the dirt and deposit in the boiler settle in the bore of the cock; this must never be permitted. *The float and alarm whistle* must be tested at times to see that it is not sticking and that it is in good working order. In addition to the float a *steam sentinel* is sometimes provided; it is set to blow off at about 2 lb. per square inch above the float whistle.

The Steam valve at the top of the boiler in connection with the main steam supply pipe should be opened and closed occasionally, to test its condition, and to ensure its being in good working order in case of any emergency arising. It may be necessary to suddenly shut off the steam at the boiler, or the connection between any other boiler; this must be done positively, and the valves kept perfectly steam-tight. These valves should be supplied with a large hand-wheel, having a handle in the rim, to give facility for closing them rapidly if occasion requires; the valve and seat, also the screw spindle and gland, should be made of gun-metal to save corrosion of these parts from the water; the flange joints should be faced in the lathe, and made metal and metal; no sheet-lead or packing material should be used for jointing.

The Feed-pump must be examined at least once a week, and the packing of the gland and stuffing-box looked to to see that it is not drawing air. The valves and the interior of the pump should also have careful attention at certain periods to see that they are in every part free from dirt or any obstruction. These precautions are specially necessary when the water forms much deposit, and also when it is from the chalk, or in the case of river water having sand or gravel deposit.

The Injector must have very careful attention, and be kept perfectly free from dirt of every description. No one but the attendant should be allowed to touch this apparatus on any account. Accidents are liable to take place when this rule is not strictly attended to.

The Feed-water Heater wants very little attention. It should be cleaned out once in every three months, or oftener if much deposit takes place; by opening the lower cock in the outer casing occasionally much of the deposit will pass out with the water before it has time to settle inside. The top cover, also the lower manhole cover, should be taken off about three times per year, to clean the interior and exterior of the tubes—also the interior of the casing. The water may be heated to 100° to 110° by this apparatus.

Blowing off Boilers.—They should be blown off once per week, and where duplicate boilers are provided they should be turned over once per month. At the time of change the flues and shells of the boilers should be examined and cleaned, and the interior also cleaned out; by attention to this rule the surface of the plates may be kept free from deposit; scale should never be allowed to form into a hard substance upon the interior of a boiler. It has been found by experience that when this rule is attended to no serious deposit takes place in the boiler, and much saving is thus effected in the wear of the plates.

Incrustation in Boilers.

Many materials have been adopted to prevent this. Those of a chemical kind, especially when they contain any acid, should never be used; common soda may with advantage be put in at intervals; refined petroleum is sometimes used in small quantities—it is very effective in preventing scale. All oil and grease should be kept out of the interior of the boiler as they cause priming; when the plates become coated with scale or deposit, those next the flues or fire are liable to be weakened by the water not being in contact with them. Heated feed-water helps to prevent scale, because much of the deposit from the water is left in the lower part of the heater, and a much purer water is thus obtained. It must always be remembered that scale inside a boiler not only very much *increases the consumption of fuel*, but deteriorates the plates and the fittings in a very rapid way. When the only available water for use is very bad, a scum-pipe may be advantageously used: this consists of a perforated cast-iron pipe fixed inside the boiler, having an open trough on the top; it is placed at about the water level; the deposit floats into the trough, and sinks to the bottom of the pipe; cocks are attached at the front of the boiler in connection with the trough; the scale is blown out when the exterior cocks are opened. The joints of the mudhole and the manhole doors must be examined at frequent intervals, to see that they are perfectly tight; leakage of steam or water at these points may cause corrosion and injury to the plates. The joint of the blow-off cock also wants careful supervision, especially as it is under the floor and not exposed to view. In the case of chalky or hard water this periodical examination of the joints is specially essential to save injury to the plates of the boiler.

Proving Boilers.—As a rule they should not be proved at a higher pressure than 100 lb. per square inch. This should be done by a hydraulic pump; the pressure should be put on *gradually;* much permanent injury may be done to the plates by *suddenly* applying heavy pressure. The pressure should remain on some time, the valves and all parts being absolutely closed and free from any leakage; all the seams of the shell and plates should be examined. Mark any place where leaking takes place *but on no account should any caulking be done while the hydraulic pressure is on the boiler.* The testing of boilers should be done in the presence and under the direction of competent people, and after the boilers are in their place periodical tests should be made, and all the parts, wherever possible, carefully examined.

Painting and cleaning.—All parts of the boilers exposed should be well cleaned and painted once or twice per year. Tar is not a good thing to put on, as there are many ingredients in it that do not suit boiler plates and are liable to do injury. Before the painting is commenced, be careful to clean away all rust or other deposit on the plates, and at the same time closely examine them to discover if any damage of importance has been done by any corrosion on their surface. This is a most important matter and should have the most particular attention, or injury of a permanent character may take place and may prove a source of danger.

General Remarks.

The different classes of boilers and their fittings having been generally described, and the best method of working indicated, it does not appear essential to enter into any other detail. Those who require further technical information on the matter, and who wish to make a study of the subject, are referred to the author's book upon 'Modern Steam Engines and Boilers,' Spon, London. In this book the details of construction are fully entered into and rules and data given of the best types to follow. The object aimed at in these and the succeeding chapters on the steam engine is to give requisite information in plain language, as free from technicalities as possible. The author advises proprietors and managers of works to select a few of the simple rules herein laid down, and have them printed and placed upon a board and suspended in a conspicuous place in the boiler house, and to enforce rigid attention to the same. Also that no person in their employment as foreman or manager of department should be permitted to give any orders as to the working of the boilers, unless he is technically well acquainted with the subject, and has had proper training in such work. The experiments of amateurs in such matters are likely to prove rather costly to the proprietors.

CHAPTER VI.

ENGINES.

ENGINES should always be placed in a house separate from the boilers, although it is advisable to have them as near the boiler house as possible, to avoid long lengths of steam pipes. The steam should be brought from the boiler by pipes covered with non-conducting composition ; the pipes should be fitted with condense boxes and also with draw-off cocks in suitable positions to draw off condensed water. It is essential that the steam is delivered to the cylinder of the engine in as dry a state as possible. It is also recommended that the engine be placed as near to the work as possible to avoid long lengths of shafting and gear. The type of engine best suited to the purpose will depend upon the space available and also upon the position where it is required to place it. Most of the different classes of engines are described that are considered the most suitable for mill and factory purposes. Those used for water pumping, especially when of a heavy character, will not be mentioned ; this work is of such a special kind that it always requires the services of a professional man to select the type of engine best suited for the circumstances.

Pumping water is, as a rule, very regular work, and for this reason greater economy in fuel is usually attained with this class of engine, than is possible with smaller engines, especially where the work is somewhat intermittent.

Mills and Factories.—Engines suitable for this purpose are of various kinds, viz.:—Oscillating (both horizontal and vertical), Vertical, Horizontal, Beam and Direct-acting engines. These are subdivided again into high-pressure or non-condensing, condensing, and compound or high and low pressure engines. A slight outline will be given of each of the leading kinds to indicate their suitability for particular purposes, after which the working and management of each kind of engine will be described, and general rules will be given to be observed in working.

Steam is conveyed in cast or wrought iron pipes from the boilers to the engines; the pipes may be wrought iron up to 2 inches diameter, above this size they should be made of cast iron with flanged joints, faced in the lathe, and the bolt-holes drilled. The length of each pipe should not exceed 8 to 9 feet; they should be covered with non-conducting composition and kept well painted, the flanges and all joints being left free to enable the attendant to detect any leakages. Connections to the engine of any kind should be made by faced surfaces, and the holes for the bolts drilled. To permit the pipes to expand without injury, "expansion" joints should be used: the best kinds are made in the form of copper discs; sliding joints do not answer—they are liable to get corroded and so may stick, and become the same as a solid pipe. It is very essential, as before stated, to get the steam into the engine as dry as possible; to ensure this, condense boxes should be provided, and draining pipes from the main supply pipes taken into them. It is advisable, whenever possible, to give the steam pipes *a fall to the boiler:* this allows some of the condense water to drain back into it. Drain cocks should also be provided to take away at intervals any condensed water not removed by the condense boxes. These cocks should always be opened before starting the engine.

Super-heaters are sometimes used to dry the steam before it enters the engine; these are, however, only of use in large engines. There are various forms of these made by different makers. The operation is in all cases a very simple one.

The working pressure of steam varies in different places; it is now usual to work at not less than from 40 to 60 lb. per square inch, 45 to 50 lb. may be taken as a good average pressure, except in compound engines when the pressure is 70 to 80 lb. per square inch. The size of the steam pipe must be properly proportioned to the power of engine. A small wrought-iron pipe should be attached to the pipe *above* the starting valve to take away the condensed water. It is most essential that the steam should be admitted *as dry as possible to the cylinder of the engine.* The exhaust steam from the engine should be taken to a feed-water heater in the boiler house, described at p. 36. The size of the exhaust pipe should be ample; all sharp bends should be avoided; also any dips in the pipes; a condense pipe should be attached at the outlet from the engine at *the lowest point* of the exhaust pipe to prevent the condense water running back to the engine cylinder. At each end of the cylinder condense cocks with pipes attached should be provided to blow out the water at each side of the piston on starting the engine; these pipes should be taken to the drain. The condense pipes from the jackets may be taken to a tank underground in cases where the hot water can be used for any purpose; the water is fit for use in the boiler—it is however, not quite pure, but sufficiently so when not required for any *delicate process of manufacture.*

The supply of steam to the engine passes through a starting valve, the quantity admitted to the cylinder being regulated by the governor and throttle valve. The starting valve may be placed full open when the engine is at work; the speed should be entirely regulated by the governor; the speed of the governor should be carefully adjusted, and all its parts kept very clean and in perfect working order. When this has careful attention, the engine will always run at a uniform speed, no matter what load or work is on at any time. If any machine is suddenly thrown out of action, the governor should at once control the speed of the engine by cutting off the supply of steam ; and, on the other hand, when any sudden demand for power takes place the valve should at once open and give the necessary supply of steam to the cylinder.

We now come to the various classes of engines in general use : the leading features of each will be described ; sufficient detail will be given to enable the reader to form a fair idea of each particular class, and thus help him to determine the kind best suited for his particular purpose. It is not intended to enter very closely into the details of construction of the various types of engines, as the subject is too large, and is also beyond the scope of this work. Sufficient detail is, however, given to enable the reader to form a judgment as to the kind most suitable.

Oscillating Engines.

For mills or factories requiring small power, and where the floor space is limited, these are a useful class of engine. They are simple in construction, and are not very liable to get out of order ; the moving parts are few, and comparatively inexperienced men can look after them. They are made both in the vertical and horizontal forms, and in some cases with the steam cylinders inclined at an angle of about 60°—when made in this way they are usually constructed with double cylinders with one crank-shaft and fly-wheel. They are sometimes made in the form of wall engines; all the parts are fixed to a strong plate, which is bolted direct to the walls of the building; in this latter case the framing should be made strong, and be securely bolted to the walls. As a rule, these engines are not used for mills and factories in larger sizes than 8 to 10 nominal horsepower. The horizontal form is most generally preferred: it should be made with a double crank, with the main bearings on each side of the bed-plate; it will thus be self-contained and be independent of the walls. The steam and exhaust pipes should be attached to gun-metal trunnion pipes, provision being made for lubrication at the glands through which the steam and exhaust pipes on either side of the engine pass. The slide-valves may be worked by a link motion—this allows the engine to run in either direction; the steam cannot be used expansively. All parts of the engine should be well balanced, the stuffing-box made long, the piston and slide rods of steel, the main bearings of gun-metal and made wide. Lubricators should be provided at all moving parts, and for the interior of the cylinder, a lubricator may be fixed on the *inlet* steam pipe; the oil then passes in with the steam. The "Porter" governor is the most suitable; it is very sensitive, and not liable to get out of order. Feed pumps for supplying water to the boiler should *not* be attached to the engine in any case: separate feed apparatus should be provided in the boiler house as described under "Boilers."

Engines of this class should be worked with steam of a pressure of at least 50 lb. per square inch, and be run at a piston speed of about 300 to 450 feet per minute. There is a great advantage in using double-cylinder engines, because the cranks are set at right angles, and thus allow the engine to be started at *any point of the stroke.* They also run more easily and regularly, and with less friction —all parts being in balance the strains are more equally divided.

In starting these engines, the condense water should first be run off the steam pipe by opening the cock *above* the starting valve ; the steam should then be let into the cylinders to warm them—the condense cocks at the top and bottom cylinder covers being opened ; then gradually open the steam valve and give full supply, and leave the throttle-valve to regulate the quantity of steam admitted to the cylinder according to the work to be done. Be sure that the lubricators are well charged with oil, and in good working order ; the pipes should be examined each day before starting, to ensure that the passage for oil is clear ; in some cases the holes get stopped with dirt, and the oil is thus prevented from reaching the bearings. When the engine is stopped for the day, drain the pipes and cylinders, and get as much of the condense water away as possible. The object should be to leave all the parts of the interior of the engine and pipes quite free of water, and as dry as possible. These engines are, as a rule, only suitable where the space is small; they are not so economical in the consumption of steam as other kinds, although they possess other advantages that in some instances outbalance this defect. They are very simple as to the working parts—hence for small power are often preferred. The foundations and fixing should be of a solid character, and the steam supplied to the cylinders should be as dry as possible. Engines of this class are very suitable for attaching direct to machines and also for working hoists and lifts by direct attachment.

Vertical Engines.

These are made as High-pressure or Non-condensing, Condensing, and Compound, and each of these types is made in several different forms, although the principle of working does not differ. The high-pressure, or non-condensing kind, is mostly used, it is made in three principal types, viz. Table, Side or A frame, and Inverted Cylinder engines. The first named has the cylinder fixed upon a low table, the piston-rod is keyed to a cross-head *above* the cylinder, to which are attached two side rods; these are connected *below* the table by another cross-head, and have a short rod keyed on at the centre; this has a strap end and brasses, and works upon the crank-pin. The crank-shaft is placed near the level of the base-plate, and runs in bearings cast upon it; the end or back bearing is in the wall of the house—the fly-wheel being next the wall; or a double crank may be used with two bearings on the bed-plate, the engine will thus be independent of the walls. This kind of engine is suitable where the floor space is small, and when it is necessary or desirable to have the crank-shaft *close to the floor.* The engines should not be worked at a piston speed exceeding 250 to 300 feet per minute, and a steam pressure may be used of from 40 lb. to 50 lb. per square inch. The wear of this kind of engine is very small; it is simple in action, works very evenly and steadily, and is not liable to get out of order. It is suitable for use when the work is steady and does not vary very much; it requires very little attention, and having no complicated parts can be easily worked by unskilled people after a little instruction. The previous remarks and those made hereafter as to fixings and foundations equally apply to this type of engine; except that what is required in this case is of a simple and less expensive character, principally on account of the space taken up, and the easy and regular working.

Side-frame Engines are made with side or hollow box frames resting upon a bed-plate, on which the cylinder is placed in front of the frame; the crank-shaft runs in bearings cast on the top of the frame. This engine is suitable when it is desired to keep the fly-wheel and crank-shaft *above* the floor ; it also has the advantage of being independent of the walls, and as it is self-contained, the driving pulley can be placed *outside* the fly-wheel ; this allows greater facility for putting on the driving belt. The frame should be very substantial, and be well spread at the feet to ensure a firm seating on the bed-plate. These engines can be run at very low speed, with a small pressure of steam, and are very suitable for temporary use in case of a break-down, as they can be easily moved and refixed ; they do not require much skill in fixing, and can be rapidly laid down ready for work. When used for temporary purposes, they may be bolted direct to a frame of timber, the latter being well secured to a good concrete foundation. Large sizes are usually fitted with expansion motion ; in this case they can be worked as economically as any other class of engine.

There are several modifications of this kind of engine ; it is advisable, however, not to use any engine complicated in any of its parts, or where all cannot readily be got at for examination and repairs.

Side-frame engines are sometimes made as condensing engines with an entablature instead of a side frame ; this is a convenient form, the air-pump and cold-water pump being worked off the crank-shaft between the columns or inside the frames ; if this cannot be done, the air-pump may be worked on the other side of the entablature, and the condenser placed near, or it may be worked direct off the piston-rod, and fixed *under* the steam cylinder.

This type of engine can be arranged for working force pumps for hydraulic machinery, and for hydraulic presses. In these cases they should be provided with two cylinders; a fly-wheel of a large or heavy size may be dispensed with; the cranks of the cylinders are set at a right angle, and so can be started at any point of the stroke. The battery of pumps can be worked direct from the crank-shaft—three or four pumps are the most suitable number to use; the crank-pins being set at different points of the stroke, they are better balanced and work more equally.

Inverted Cylinder Engines.—These are made in the same way as at p. 59, except that the cylinder is fixed on the top of the box frame and *inverted*, and the crank-shaft is placed near the bed-plate level, with one end working in a bearing cast on the bed-plate, and the other in a wall-box in the wall of the engine house. The fly-wheel is keyed on near the wall, and the driving pulley between it and the bed-plate. In some cases the crank is made double and runs in two bearings which are cast on the bed-plate; the engines are in this case self-contained, and are more convenient for fixing quickly and removal when done with. The fly-wheel in this type is placed next the bed-plate and the pulley outside. This kind of engine is not always to be recommended, as the packings give some trouble; and in some other respects they are not such a desirable class of engine as some of the former named. They are seldom made for mills and factories in larger size in this form than 15 to 20 nominal horse-power.

They are sometimes built with triple cylinders and worked as compound or high and low-pressure engines. In this form they are also useful for working high-pressure pumps tc supply hydraulic machinery. They are also suitable for working blowing and ventilating apparatus; they are in this case coupled direct to the machine; the engines have to be specially arranged for this purpose. This type of engine is also much used for driving dynamos for electric light machinery, more especially when the floor space at command is limited. They can be worked at a high speed; all parts are easily accessible for repairs and the necessary adjustments.

Willan's Patent Engines.—These are made in the form of inverted cylinder engines; they are single acting; the whole of the work under the cylinders, including the crank-shaft, is enclosed in a box of cast iron; the engines are built with two cranks, in tandem form coupled, and worked as compound engines; the stroke is usually not more than 6 inch or about one-half the diameter of the low-pressure cylinder. The pressure of steam used is about 95 to 100 lb. per square inch, and the speed 450 to 500 revolutions per minute, or say about 750 feet per minute piston speed. The steam is let into the top or high-pressure cylinder and expanded into the lower or low-pressure cylinder, —the steam used is about 27 lb. per I.H.P. The crank-shaft bearings are made in lengths equal to $2\frac{1}{2}$ to 3 diameters of the shaft. They are also built as triple expansion tandem engines, and are worked in this case with a steam pressure of 140 to 150 lb. per square inch. They are principally used for the direct driving of dynamos, for electric light machinery, blowing machines, fans for furnaces and centrifugal pumps. When used for driving ventilating fans for mines, &c., they are run at a lower speed. They are also used for steam launches, and other purposes where direct action can be applied and where a high speed is required. They are very economical in working and only want ordinary attention. The object of closing the working parts in an iron casing is to protect the reciprocating parts from dirt and to facilitate oiling all parts efficiently; it is claimed that much less oil is used than on the ordinary engine, and that the dirt attendant upon the splashing of oil in high speed engines is avoided. The bearings of the connecting rod and other moving parts seldom want any adjustment, and the engines are very compact and do not require an expensive foundation. They are sent away from the works complete and ready for placing on the foundation; all parts are made in duplicate, so as to be readily and expeditiously replaced when necessary. There are several other forms of these enclosed engines made; the author, however, considers those described are the most efficient, and to be recommended for cases they are suited for.

There are many other modifications of vertical engines, but as they are not often used they do not need any detailed notice. It is impossible to give any fixed rules as to the choice of engines of the vertical type beyond what has been indicated above —circumstances must decide the most suitable form to adopt.

Horizontal Engines.

High-pressure or Non-condensing Engines.—This form of engine is the most useful kind, and is to be recommended in preference to other types, except in cases where the floor space is limited, when a vertical engine should be used. Horizontal engines being so well known, much description in detail does not seem needful. For sizes above 8 horse-power nominal an expansion slide should be provided, with variable adjustable gear. All the rubbing or bearing surfaces of the engine should be large; it must be borne in mind that *friction is not increased* by extending the surfaces. The best form of guides are those cast on the bed-plate on each side, with sliding guide-blocks working between raised edges to retain the oil. The piston and slide rods, also the cross-head and crank-pin, should be made of steel. The stuffing-box of the piston-rod should be made long, and when the size of the cylinder exceeds 16 inches diameter, a stuffing-box at the back cover with a back piston-rod should also be provided. A crank disc, balanced at the back, is preferable in most cases to a crank. The fly-wheel should always be bored out at the boss, and fitted with two keys, in beds sunk in the crank-shaft; the rim and edges of the wheel should be turned and carefully balanced; the boss should be cast split, and after it is bored out it should have wrought-iron hoops shrunk on each side. Condense cocks and pipes should be fitted at each end of the cylinder, as before described. The cylinder should be provided with a grease cock to lubricate the inside, and provision should be made in the covers of the cylinder and other parts for indicating the work done by engine when required. The cylinder should be bolted to the bed-plate by four or six turned bolts, according to the power of the engine; it should rest on planed surfaces, and be fitted between joggles cast on the bed-plate. All moving parts should be provided with check nuts, and in some cases they should also be cross-pinned to prevent any part from working loose. The governor should be Porter's patent high speed; careful attention should be given to perfect adjustment of the speed, also to all the levers and joints, to ensure that it works without any undue friction. These engines may be run at a speed of 300 to 400 feet per minute, and the steam may be used from

60 to 70 lb. per square inch. Observe the same rules in starting and stopping the engine as before named.

Horizontal Condensing Engines.—The most usual form of these engines is for the air-pump and condenser to be fixed at the back of the steam cylinder, and worked direct off the piston rod at the back cover. The condenser in this case usually surrounds the pump. The cold-water and circuculating pump is worked off the cross-head of the engine. Variable expansion slide-gear is provided. All the fixed parts of the engine should be attached to one cast-iron bed-plate. The manner of working these engines, being so well known, need not be described. Engines of this class can only be used with advantage where there is a plentiful and cheap supply of water for the purposes of condensation; they are economical in action, and effect a saving in fuel above the non-condensing engines just described. The piston speed should not exceed 220 to 240 feet per minute; the pressure of steam may be 50 to 60 lb. per square inch. Expansion slides should be fitted to the engine; the cut-off will be regulated by the work; it is usually made at a quarter to two-thirds of the stroke of the piston.

There are several modifications of this type of engine, depending upon the floor space at disposal; when this is limited, the air-pump can be worked either off the cross-head or the crank shaft, and arrangements made to facilitate getting at all the parts in case of adjustment or repairs being necessary. Surface condensers may often be, with great advantage, added to this kind of engine, even in cases where the water supply is not ample. This is of necessity a matter that must be dealt with by skilled hands.

Horizontal Compound Engines.—These are a favourite form for large engines: they are less costly in the first instance than the beam kind; they are usually arranged with the high-pressure cylinder in front, the low-pressure cylinder behind, and the air-pump and condenser beyond this. They of necessity take more floor space, and can only be used where there is sufficient room; they are more simple in construction than beam engines, and, having fewer moving parts, are less liable to get out of order. Engines of this class are also made coupled, with the high-pressure cylinder on one bed-plate and the low-pressure cylinder on the other, with one crank-shaft and fly-wheel common to the two engines; the air-pump in this case is worked at the back of the low-pressure cylinder, and the cold-water and circulating pump at the back of the high-pressure cylinder; one governor controls the two engines. These engines give the highest results in working, and are very economical as to the fuel consumed in the boilers. There are many forms of compound horizontal engines, but the main features and system of construction do not much differ. The particular circumstances of the case must decide the best form of engine for the purpose. As a general rule compound engines are not suitable for rapid working, or where the load is very irregular; they give the highest results when pumping water, blowing air for blast-furnaces, and for ventilation of mines, or doing ordinary steady mill work. Compound engines require the attention of skilled men; their construction and working is not so simple as the other kinds of horizontal engines described.

Foundations.—In all the types of the horizontal engines named, the foundations require great care, as on a solid base very much depends the even working of the engine, and the consequent wear of the parts. When the bottom soil is indifferent extra concrete must be used; the brickwork should always be built in Portland cement, and the base stone of any hard quality that can be obtained in the locality. As a rule York stone is the most suitable where the expense of carriage does not prevent its use.

Beam Engines.

High-pressure Beam Engines.—These engines are still preferred by some people, and are very efficient in working; their form does not vary much. The beams may be made of wrought or cast iron, and with single or double cheeks. The connecting rods should be wrought iron or steel, the piston and slide rods of steel as before. All the fixed parts should be attached to a strong bed-plate resting on a good foundation stone, with brickwork and concrete under it. The cylinder should be provided with variable expansion slide-gear.

All the parts of this class of engine are in perfect balance; it is specially suitable for pumping water, and in cases where the work to be performed is regular. The pressure of steam used should be about 50 to 60 lb. per square inch, and the piston speed about 220 to 250 feet per minute. In starting these engines, especially when of large size, first drain all the condense water away from the pipes and cylinders, then slowly open the starting valve, to well warm the cylinders with steam, and to allow the parts to expand slowly by the heat. All parts of the engine should be well lubricated—the joints of the parallel motion require particular attention. For starting the engine when on the dead centres, a rack plate and bar should be provided, or a ratchet or rack may be cast on the rim of the fly-wheel, and a lever working on a fixed fulcrum may be used. The back bearing in the wall should have a pipe carried to the front of the wall, to allow of easy lubrication. Be very careful as to the condition of the lubricators and grease cups—that they are kept clean, well filled with oil, and in perfect working order. The bright parts of the engine should be cleaned *before starting each day*, and all the nuts and pins tried, to make sure they are in good order, and that nothing is loose.

Condensing Beam Engines.—These are constructed in the same way as the high-pressure described at p. 67, except that an air-pump is worked off the beam about midway between the main centre and the connecting rod; the pump is usually half the stroke of the cylinder; the condenser is generally placed at the side, and the hot well on top of the air-pump. The cold-water pump to supply the condenser is worked off the beam also. The pressure of steam should be about 50 to 60 lb. per square inch, and the piston speed about 220 to 250 feet per minute. A good supply of clean water, free from deposit, and at a cheap rate is essential to these engines, otherwise the cost of working will exceed non-condensing engines.

The same remarks as to working, the kind of foundations, and other details named above, also apply to these engines. The surface condenser named at p. 66 equally applies in this case. Engines of this class occasionally somewhat differ in their arrangements, but the action is the same in all cases.

Compound High and Low-pressure Beam Engines.—These engines are made in much the same way as the last described, except that they have two cylinders, one for high pressure and one for low. The steam passes first into the high-pressure cylinder, and then exhausts into the low-pressure cylinder, from which it is discharged to the condenser ; the cylinders are generally worked close together at one end of the beam. These engines are only suitable for large sizes ; they are very economical in working, and are specially adapted for driving mills and pumping water for towns, or pumping sewage. They are sometimes coupled, the high-pressure cylinder being worked by one beam, and the low-pressure cylinder by the other, with *one* crank-shaft and fly-wheel common to the two engines ; this is placed between the engines ; in this case the steam passes into an intermediate receiver. The cold-water and circulating pumps are worked by one beam and the air-pump by the other. Engines of this class are specially suitable for pumping water, and are very efficient in action ; in cases of this kind they work slowly and steadily ; the work as a rule is constant, and on this account there are no sudden shocks to the engine ; they are peculiarly adapted for waterworks purposes. The consumption of coal at some of the London waterworks where this type is used is not more than $1\frac{3}{4}$ to 2 pounds per indicated horse-power per hour. When these engines are used for pumping, the pumps are usually placed at the crank end of the beam ; they are made double-acting, and on the ram and piston plan ; the valve-boxes are placed below the bed-plate ; bonnets are provided at the suction and delivery valves to allow easy and rapid examination. The rules mentioned hereafter, to be observed in working these engines, do not much differ from the last type ; only competent men who have special experience should be employed to attend to them. The first cost of this kind of engine is much more than those previously described, but when well looked after, the economy effected in the consumption of coal by their use well repays the extra outlay.

This type of engine is more complicated in its parts than those before described, and is not used except when large engines are required; they want much more care and skilful attention. They are usually worked with steam at 70 to 80 lb. pressure per square inch.

Working the above Engines.

The same rules will apply to most kinds of condensing engines. Before starting, the cylinders should be warmed by steam and cleared of condensed water by opening the cocks at the bottom of the steam and exhaust pipes, also the cocks at each end of the cylinder. The grade of the expansion slide should be set according to the work to be done; if this does not vary much from day to day it need not be touched when once set. See that the lubricators are well filled with oil, the cottons in good order, and the holes clear of dirt. The main slide of the engine should be worked to and fro by the hand-lever on the weight-shaft, the eccentric rod being thrown out of gear by means of the gab end; the cylinder at each side of the piston is thus thoroughly warmed by the admission of steam ; it also enables all parts to expand slowly, and so prevents the starting of any of the joints. See that the injection water (in the case of condensing engines) is ready, and then slowly open the starting valve to its full extent, observe the vacuum gauge and adjust the injection water. When the cylinder is jacketed, admit steam into the jacket at the time of warming up ; the condense water from the jacket should drain back to the boilers. When in good working order the vacuum made in the condenser should be 27 inches. The consumption of fuel should be about 3 to 3½ lb. per indicated horse-power per hour ;—this consumption only applies to engines of the highest class of manufacture.

All the gun-metal bearings, caps, and keys of the moving parts should be examined each day before starting; make sure that all parts are bearing fairly, also that they are getting free and sufficient lubrication. Test the level of the crank-shaft at certain periods by placing a spirit level on top of the shaft—this will show the condition of the back bearing ; if any part of the engine runs hot it is a sign of undue friction in some part, and should have immediate attention. The engine should be indicated on certain occasions to test the actual work it is doing ; as, however, this operation requires much care, it can only be done by experienced people.

The piston should be drawn at least once each six months, and the air-pump bucket and valves examined ; the cylinder slides should also be looked to, and adjusted if necessary. The connecting-rod bearings should be examined and closed up if slack. The main-bearing brasses in all well-made engines of any size should be adjustable, so as to take up the wear in any direction and maintain the exact level and position of the crank-shaft. The back bearing of the crank-shaft in the wall should be easy of access, not only for lubrication, but for examination and adjustment of the gun-metal bearings and holding bolts.

The oil used should be of the mineral kind. Lard or other animal or vegetable oils are not suitable for lubrication, as they coat or gum up the bearings and make the moving parts run heavily. Tallow, unless it is of the very best quality, should not as a rule be used, as some of the fats contain acid and are injurious to the interior of the cylinder, piston, and slides, &c. The stuffing-box packings must have the most careful attention ; common hemp packing is about the best kind to use ; the glands should be fitted, whenever possible, with three studs, to ensure an equal amount of pressure being put on the packings all round, and also that no undue friction is placed on any part of the rods passing through the packings and glands ; no leakage of steam should be permitted at the glands. The oil from the piston and other rods should be caught in shallow copper trays ; the refuse should be used for other purposes, but *not* for lubricating the engine—pure and only perfectly clean oil should be used.

The engine should be painted, and twice varnished when laid down; when this is well done it will last for several years, and can be easily kept clean by wiping down each day; the varnish prevents the oil from sinking into the grain of the iron; a coat of varnish once in every two or three years will keep the engine in good order.

Condensing engines require more skilful and careful attention than high-pressure or non-condensing engines; the moving parts are more numerous, and the operations of the engine require more personal attention. The driver should carefully watch the steam and vacuum gauges in order to detect any defect in any of the working parts. The engine should be well oiled at each stopping time, and all parts kept perfectly clean.

Cornish and Direct-acting Engines.

These are principally used for pumping water, and are somewhat of a complicated nature; they are very economical in action, especially as to the consumption of fuel; they are, however, only suitable for large powers and for special circumstances. As they are not adapted for mill or manufacturing purposes no description will be given. Any one desiring any detailed information as to these and other kinds of engines is referred to the author's books upon 'Pumps and Pumping' and 'Modern Engines and Boilers." *

* 'Pumps and Pumping,' and 'Modern Engines and Boilers,' by F. Colyer, M.I.C.E. London: E. & F. N. Spon.

Worthington Pumping Engines.

These engines are principally used for pumping water on a large scale; they are direct acting and *not rotative;* they are very economical in their action and have been brought to a great state of perfection by Messrs. Simpson and Co., Ltd. They show greater economy than any other kind of engine in the consumption of coal and the steam used. They require much less foundation than any other type of pumping engine, and also a much less costly engine house. They are made with two steam cylinders and two double acting pumps. The speed is adjusted to the requirements of the work by a most ingenious automatic arrangement, the invention of Mr. J. G. Mair-Rumley, M.I.C.E. It is not intended to give more than an outline of these fine machines, it being far beyond the scope of this book: they are noticed to make the general outlines of engines given complete. For details of these engines see 'Pumps and Pumping' (Spon).

Steam Pumps.

Pumping water in many mills and factories is conveniently done by independent self-contained direct-acting steam pumps. There are many forms of these made. The author has used with much success for many years the "Model" steam pump made by Messrs. Thornewill and Warham, Burton - on - Trent. They are well designed, efficient in working; all the parts can be readily got at for examination and renewal of valves, also for repairs. They will work at a low or high speed and give a regular stream of water; they require very little attention. They can be applied to well pumping when the level of the water is within 20 to 25 feet of the surface; a steam pipe, properly protected, can be taken from the main boiler. Pumps of this description are specially useful when it is required to pump up liquids from one vessel to another. They can be placed close to their work; all long lengths of shafting and gear are avoided; and much expense is saved in the cost of same, as well as in the working of the pump.

PULSOMETERS

Do not strictly come under the head of engines, as these machines act directly by steam without the aid of any machinery. They are very useful for pumping from excavations, coffer dams, and for all temporary work; they will work suspended at almost any depth; the consumption of steam is not large. They will draw water 13 feet below the valves, and are capable of raising it 80 to 90 feet high. The length of the horizontal suction does not affect the working of the pump; the pipes must, however, be made of ample size to prevent friction. The pump will work under water; the steam is conveyed, in the case of wells and excavations, by means of an india-rubber hose. No exhaust pipe is required. The smallest size pumps 600 gallons per hour, and the largest 65,000 gallons—the size of the suction pipe in the former case being $1\frac{1}{2}$-inch, and in the latter 10-inch diameter; the discharge pipes are respectively 1-inch and 8-inch diameter.

Gas Engines.

This book would not be complete without an outline description of these machines. Engines of this kind are only to be recommended where a steam boiler cannot be used, or where steam cannot be conveniently procured from a boiler within a reasonable distance. They are not so economical in working as an ordinary steam engine; there are, however, cases where it is practically impossible to employ any engine worked by a boiler of any kind. In cases of this description the extra cost of working is counterbalanced by the advantages, convenience, and comparative economy obtained over working by manual power. One objection to their use is the noise in working; this would be fatal in many instances and should be carefully considered before deciding to adopt them.

The engines are constructed as to the principal parts in somewhat the same form as an ordinary high-pressure steam engine, and are built both as single and coupled engines. The cylinder is specially constructed : it is surrounded with a water jacket, and must be provided with an ample supply of water to keep it cool; the piston and rod, guides, connecting rod, crank, and fly-wheel, are made much in the same form as a steam engine. Coal gas as supplied by the gas companies can be used, but in places where Dowson's gas can be obtained the cost of working is much reduced.

The cost of gas used for working these engines is given at p. 107 under the head of "Rules, &c." The foundations required are not so heavy as for an ordinary engine. The small sizes up to 4 N.H.P. can be fixed to strong joists or timbers, unless iron girders are available and can be utilised ; the engine should be disconnected as much as possible from the walls or foundations of the building in which it is placed to prevent vibration and noise.

Rotary Engines.

There are several types of this form of engine; they are used for driving dynamos for electric light machinery, centrifugal pumps, hydro-extractors, fans for smithies, &c., and other kindred purposes, where it is required to drive at a high speed, *direct* from the engine and coupled to the machine. The best kinds are the Tower, the Fielding and Platt, and the Multiple Steam Turbine by the Hon. C. A. Parsons; the latter is, however, only suitable where a very high speed is required; they run up to 9000 to 10,000 revolutions per minute. Brotherhood's three-cylinder engine may also be considered a rotary engine, and is one of the best of this class. These engines are used to drive dynamos, fans for ventilating, centrifugal machines, for steam launches, and also for various ship purposes, such as working capstans, &c. They are also employed for propelling torpedoes by compressed air. In this case they only weigh 30 lb. and give 20 actual H.P. The author believes these to be the most successful rotary engines that have been produced. Some of this type of engine of the larger kind, worked on the compound system, do not use more than 20 to 25 lb. steam per I.H.P. Not any rotary engine works as economically as an ordinary engine—the consumption of steam per I.H.P. is much higher. One great advantage is their portability, light weight, and facility with which they can be attached direct to any machine they are intended to drive. They give a very high speed with a steady motion; the vibration is very small, and they are usually silent in working. There are several other forms, some of which are not efficient in working, and others have not passed much beyond the experimental stage; they have not, therefore, been described. Only engines that can be recommended for use have been mentioned in this book—no theories have been discussed in reference to the respective merits of the different designs.

DAVEY'S PATENT MOTOR.

This is a small power engine of very simple type; it is principally suited for domestic purposes and for small public institutions, where pumping water and other light work is to be done. It is built in the vertical form and is combined with the boiler; the whole stands upon a bed-plate and is self-contained. It is a very simple engine to work; any unskilled person can attend to it; and as there is no pressure in the boiler it can be worked with the most perfect safety; it requires very little attention, and if neglected no accident can take place. There is nothing to get out of order; the furnace need only be fed three or four times per day, and even less than this in some cases. It may be employed to drive washing machinery for a laundry, bread-making, electric light and pumping machinery, or in any case where small power is needed. The consumption of fuel is about 6 lb. of gas coke per I.H.P. per hour; the consumption of steam is 30 lb. per I.H.P. per hour. The machine can be delivered ready for bolting down either to a floor or on a timber or brickwork foundation; it does not require skilled labour to fix it. The risk from fire to any building where it is placed is no more than from an ordinary house fire; any small chimney is sufficient for the furnace, and but small draught is required. It is one of the most useful machines for small powers that has been brought out for many years; it is entirely free from any of the difficulties that arise in the use of hot air engines. It weighs but little, and can be readily transported from place to place when required.

It is made in sizes from one to six H.P. There are no instructions to give as to working the engine—they are so simple they would be learned the first day of using it.

Hydraulic Engines.

This type of engine is noticed although there are not many cases (except where only small power is required) where they can be employed. In towns where water under high pressure can be had from the public street mains, they may be used for driving small lathes for dentists, watch makers, and other light work; also for working light lifting machinery. One of the best forms is the three-cylinder engine before described by Mr. Peter Brotherhood: it is simple in construction, occupies small space, and works in a perfectly satisfactory manner. No hydraulic engine can be worked as economically as a steam engine; there are, however, cases in which this would not be a consideration, when the advantages they present are considered, viz. no attendant is required for them; there is no risk from fire; no dirt or heat; very little expense for oil or for repairs; they require no expensive foundations, as they can be bolted to timber or any strong floor. Any pressure above 50 lb. per

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square inch will work them with comparative economy. In cases where the Hydraulic Power Company's mains are near much economy of working will be effected, and engines of larger power can be employed. In London and Liverpool the charge for water power from the companies' mains is very moderate.

Electric Engines or Motors.

These machines scarcely come under the head of ordinary engines, but as they are now (1891) being brought more into use, owing to many improvements lately made in them, and also because the power to work them can now be obtained at a moderate rate from electric cables laid in the public streets, a short sketch of them may be found useful. It is not, however, intended to enter into any detail as to their construction or to discuss the merits of the various forms in use—they are only noticed because they are useful machines to adopt in some special instances, such as for domestic use in driving sewing machines, boot cleaning, bottle washing, small-power lathes, and other light work. They may also be employed by dentists to drive their light lathes, ivory turners, watch makers, and other classes of work where small mechanical power is required. The economy of working as compared to other systems cannot be discussed until further experience of their performance has been acquired; the question of cost, however, does not much affect their adoption in the above-named cases, as their usefulness and economy as compared to manual labour is undoubted. There is no doubt that many improvements will be made not only in the motors, but in the reduction of cost in the electric current supplied to work them by the Electric Power Companies. In places where dynamos and plant for the electric light are laid down, power for working machines by electricity can be had at a cheaper rate than from such companies.

Special Engines.

Blowing Engines for iron and steel works.
Air Compressing Engines for driving machines.
Ventilating Engines for mines and tunnels.
Winding Engines for mines and tunnels.

All of this class of engine are of a special character and are usually of large power. They are made in the vertical and horizontal forms, and to work as high pressure or non-condensing, condensing, and compound, or high- and low-pressure engines. All of these are rather complicated in construction, and would require a lengthy description and of a more technical nature than for ordinary engines to make the reader understand sufficiently to select the type most suitable for his purpose. As a rule, in cases of this kind professional assistance should be obtained. It is beyond the scope of this book to enter into detail of these important machines. Any one requiring further information is referred to the author's book upon 'Modern Steam Engines' (Spon), and also to 'Pumps and Pumping Machinery' (Spon): in these books the subject is fully treated and ample drawings given of various types of each of this kind of engine.

Portable Engines.

Under this head may be classed the following :—

Portable Engines and Boilers for driving sundry machines.

Portable Pumping Engines and Boilers for temporary pumping of excavations, &c.

Portable Steam Fire Engines for extinguishing fires.

Traction Engines for moving loads on common roads.

Ploughing Engines for agricultural purposes.

These engines and boilers are made combined, and are mounted on wheels—the two latter named being self-propelling; the three former are moved from place to place by horse-power. All of this special class of engines are made in perfection by the under-named firms; users cannot do better than send their requirements to them, stating the purposes for which the engines are to be used, and if to be worked high pressure with single or double cylinder, or on the compound or high- and low-pressure system, and get an offer from them. For portable engines: Messrs. Clayton, Shuttleworth, and Co., Lincoln ; Ruston, Proctor, and Co., Lincoln ; Ransome and Co., Ipswich ; Davey, Paxman, and Co., Colchester ; and Marshall and Sons, Gainsborough. For portable pumping engines : Messrs. G. Waller and Co., London. For steam fire engines : Messrs. Shand, Mason, and Co., Southwark ; and Messrs. Merryweather and Sons, Greenwich. For traction and ploughing engines : Messrs. Marshall and Sons, Gainsborough ; Fowler and Co., Leeds ; Aveling and Porter, Rochester. No particular description of the above engines is necessary, nor is it essential to enter into any details as to working, because there is nothing very special in their treatment beyond what has been stated for other engines and boilers, added to the instructions given by the makers. As there are only a comparatively limited number of makers of these engines, and as the details do not materially differ from each other, the author thought it the easiest plan in this instance to mention the best makers to ensure proprietors of mills, &c., getting the best value for their money. Those who prefer to go into further technical details in relation to the same, are referred to the two books of the author named on p. 74.

CHAPTER VII.

FOUNDATIONS OF ENGINES AND ENGINE HOUSES.

The foundation of an engine requires the most careful consideration. A good bottom must first be obtained; the depth of the foundation and the excavation under ground will, of course, depend upon the power and class of the engine. When a sound bottom is arrived at it should be well rammed, and a bed of concrete laid from 18 inches to 24 inches thick, and on this a brickwork foundation built with Portland cement; the footings should be two courses (6 inches) thick, and four courses (24 inches) deep. A Portland or Yorkshire stone about 18 to 24 inches thick, according to the size of the engine, should be laid on top of the brickwork, made perfectly level and bedded in cement; the bed-plate of the engine is then to be firmly bolted down by long bolts, passing some depth into the brickwork; when the engine bed is levelled and bolted up, the bolts should be run up with Portland cement grout. The stone should be squared, tooled, rubbed on the top and on all sides, and hacked to a fair, even, and level bed on the lower side; the top must be made perfectly level, and before the bed-plate of the engine is put down it must be trued up to a perfect surface, *dead* level. The lower part of the engine bed-plate should be planed to ensure it having an even bed on the stone. Pockets for the cottars or keys of the holding bolts should be left in the brickwork; the cottars should bear upon cast-iron plates, and these on stones 6 to 9 inches thick, built across the foundation. In marshy districts piles should be driven to the firm ground, and a platform of timber made on top of them; on this concrete should be laid. Skilled advice should always be obtained for the foundations of engines and machinery, as it must be borne in mind that upon the firm and unyielding character of the foundation will depend the accurate working of the engine, and the consequent reduction of wear, and cost of repairs; a good solid foundation is a good investment for the future. After the bed-plate of the engine has been made perfectly level, and the bolts run up with cement grout, the work should stand for at least two weeks to allow the brick and stone work to dry, otherwise the working of the engine may do permanent injury to it before it has had time to set. Experience has shown that cement work increases in strength by time, and if the joints are disturbed or broken before they are set, the work is destroyed. The foundations for the larger kind of beam engines are not such a simple matter as that described above; arrangements have usually to be made under the floor line for the air-pump, condenser, and in the case of pumping engines also for the pumps and valve boxes, as well as the pipes. When the engines are of large power the foundation stone should be granite—it is much more expensive, but well repays the outlay after the lapse of years; in these cases the granite stone is usually only placed under the cylinder, the main column, the crank bearings, and any other parts that have a direct bearing on the foundation.

Temporary Foundations for engines may be made by forming a block of concrete of about 2 feet to 2 feet 6 inches in thickness, and then fixing a frame of timber on top of same. The engine bed may be bolted direct to the timber, the holding-down bolts passing through the timber and the concrete; the bolts are built in as the concrete is formed. When a temporary engine has to be put down upon a marshy site piles may be driven and the timber frame bolted to the top of same; about 24 inches thick of concrete should be laid between the piles to steady them.

In cases where engines have to be fixed to gantries or jetties, a timber frame may be formed, and the engine placed upon the top. In a case like this it is better to use whole timbers to ensure steadiness.

ENGINE HOUSES.

The construction of these will depend upon the class of engine, and the purposes for which they are to be used. For engines of ordinary size the walls of the house should be 14 inches or 1½ brick thick, and the height from the floor line to the wall-plate about 12 to 14 feet. The roof may be constructed with wood or iron trusses, close boarded, felted, and covered with slates. The walls may either be whitewashed or plastered and painted; the latter plan is the better—it is cleaner and more economical in the end. In a good class of house the walls may be lined with white glazed bricks, bands of colour being introduced at the wall-plate and also to form a dado—this takes the glare off the eyes. The floor may either be wood, stone, or Stuart's granolithic paving; the level should be at least 12 inches above the outside ground line, to keep the place dry. The windows should be a good size, and afford plenty of light and ventilation when required; the door may be half glass. The dimensions of the house will depend upon the size of the engines: when duplicate engines are provided a space of at least 6 feet to 8 feet should be left between each. The minimum space between the stone bed and the walls of the house should not be less than 4 feet; this gives room for the fly-wheel and driving pulley. Sufficient room must be left at the cylinder ends to draw the piston and rod. In large engine houses provision should be made for lifting the cylinder crank shaft and other heavy parts.

Channels for Pipes.—If there are any pipes under the floor line, brickwork channels should be built to receive them ; the side walls should be 9 inches thick, the bottom paved with stone, or it may be made of concrete cemented on the top ; it should be laid to a fall to keep it clear of water. The width between the walls should not be less than 14 inches—this will much depend upon the size of the pipes ; ample room must be allowed to remake the joints when necessary. The top should be covered by loose cast iron plates let in flush with the top of the floor, a rebate being made in the floor (if stone) to receive them ; or 1½-inch L iron will do very well when the floor is of wood or granolithic cement paving. The floor covering is stopped at the L iron, and the plates when shifted do not wear away the edges of the boards or other covering. In some cases a glazed lantern in the roof is advisable to give top light and also good ventilation.

Fittings for the Room.—Vacuum and steam gauges should be fixed on the walls at a spot where the man attending the engine can easily read them. A set of spanners should also be placed on a rack fixed on the wall : a sufficient number should be supplied to take every size of nut ; key and socket spanners should also be provided. These spanners *should not on any account be allowed to be removed from the engine house*, as in case of a sudden emergency they might be out of the house or mislaid, and an accident or stoppage caused, which might be of serious consequences, and entail heavy loss. When a work bench cannot be fixed in the boiler house it may be placed here, and be provided with a vice bench with a drawer, also a cupboard for tools.

The Oil-cans should be kept on a copper tray on a table close to the engines; two or three different sizes and descriptions of cans should be provided to enable the driver to safely and conveniently reach all parts of the engine.

An Engine Counter should be provided to record the number of revolutions made by the engine, and in the case of pumping engines the quantity of water pumped, and the "head" or pressure of the water should also be recorded. In some cases a continuous record is kept by an apparatus having a cylinder to which a roll of paper is attached; this is worked by a clock; it shows the work done at any particular hour, and also the work from day to day. The cylinder and roll of paper are locked up, and cannot be tampered with by the engine driver; this plan is useful as it gives a permanent record of the work done.

A Cupboard should be provided for the driver to keep his tools, wipings, and other materials in; he should have a chisel, hammer, a few files, a shifting spanner, and a pinch-bar. Spare oil and cotton waste may also be kept here, unless there is a store room in the works.

Electric Bells should be fixed on the walls of the engine house, with a series of dials or indicators communicating to various parts of the mill, or factory. A message can be sent from any part telling the driver to start, stop, or run easily; this plan is much preferable to common bells or gongs worked by a code of signals, according to the number of strokes, as mistakes may arise by this system. The electric system above recommended is specially desirable because the man can *see* the message, and can then be in no doubt as to the order intended to be conveyed; the author has used the system for some time, and can confidently recommend it for perfect working.

Rules for Working should be printed, framed, and placed upon the walls of the engine house in a conspicuous position; these should instruct the driver what his duties are, and also what he is to do in case of emergency. The rules should be in clear and concise language, so as not to leave the man any excuse for not understanding and rigidly obeying them. By strict observance of proper rules, accidents may be prevented, as well as undue wear of the machinery and gear. The author believes that many of the accidents to machinery that take place might be prevented by a more perfect system of working as far as the men are concerned.

Cleanliness and a trim appearance both in the room and the machinery should be insisted on; it will be found that men take a pride in the machinery when this is carefully attended to, with the result that the wear is much less, and the chances of a breakdown are very much reduced.

The engine room of a mill should be the show place of the establishment, and the perfection of cleanliness and order. From a long experience the author has found the best drivers and attendants are usually in the best kept engine room.

Strangers should not on any account be allowed in the engine or boiler houses unless by special permission; and no one except those in charge should on any pretence be permitted to interfere with the engine or any part of the machinery. This rule should be at all times rigidly adhered to.

Engine Drivers.--A system of rewards to the men for the trim and good condition of the machinery will induce them to keep all in perfect working order ; a careless man should on no account be entrusted with an engine of any kind. It need hardly be said that, in the case of large engines, serious loss may take place, and possibly injury to human life, by the want of proper knowledge, carelessness, or neglect of the driver. A man who is personally clean will, as a rule, keep his room and machinery in the best condition, and be orderly and systematic in all that he does. Long spells of duty should be avoided whenever possible, as from natural fatigue and the enervating air of the room the men are sometimes so tired they cannot well perform their duties in a proper manner. The class of man employed to drive engines will depend upon their power and description : compound and large beam engines of all kinds, as a rule, require the services of an experienced man, not only conversant with driving the engine, but one who has fair knowledge of the details of the various parts. Such men will sooner discover any radical defect in the engine, and by taking proper precautions in time may save a serious breakdown and consequent stoppage to the machinery. This is a matter of great moment in most mills and manufactories, as much loss of time and labour may be caused by such stoppage. A well-paid man is generally a good servant, and one likely to care for the machines under him. In large establishments, where a foreman engineer or fitter is kept, the stoker and engine driver should be placed under him and only allowed to act under his direction; in such establishments the attendant at the engine has no work to do in the boiler house. The number of hours the engines are running each day should be recorded as well as the number of revolutions made in the time, and the average working pressure of the steam through the day. In some places it is also desirable to keep a record of the quantity of injection water used. In the boiler house a record should also be kept of the coals burned per day and the number of hours steam has been supplied.

Most of the necessary working details of engines and boilers have been touched upon, except for cases of a very technical nature, and which are beyond the province of this work. In the author's book upon 'the Modern Steam Engine' (E. & F. N. Spon) will be found details of all the best forms of engines and boilers; their construction is fully treated; the working data and the results of performances are also given. To this book all readers desiring more detailed information as to the construction of such machinery are referred.

CHAPTER VIII.

SHAFTING AND GEAR TO DRIVE MACHINERY IN MILLS AND FACTORIES, ETC.

The shafting and gear for driving the various machines in a mill or factory are of the greatest importance. Much care should be used in making the requirements known to the manufacturing engineers, especially in cases where tenders are being invited for work. When the enquiry is made details of all the leading particulars should be given to those who tender. All are thus placed upon a fair basis, and the proprietor is more likely to get what he wants done in a more efficient and sound manner, and will thus get full value for his money. The following particulars are given with a view to help proprietors and managers to select the requisite gear suitable for their particular case. The heaviest machines should be placed, where possible, near the engine, so as to avoid waste of power and extra expense in long lengths of shafting.

Shafting.—The diameter will depend upon the speed and the power to be transmitted. Assuming this to be decided the work should be carried out in the following manner: The shafting should be turned to Whitworth's gauge, and have bearings at about 7, 8, or 9 feet according to the positions of the machines to be driven and the power required. The driving pulleys or tooth wheels should be placed near a bearing; and at this point two loose collars of steel must be provided, fitted with countersunk screws. The plummer blocks must be lined with gun-metal, and be from $1\frac{1}{2}$ times to twice the diameter of the bearing in width; they must each be fitted with oil lubricators, also with oil pan or receiver. The bearings must be carried in wall boxes, hangers, or on brackets to suit their relative positions.

Wall-boxes, Brackets, and Hangers should have their seatings faced, and be provided with joggles and keys, to adjust and to fix the plummer blocks attached to them; they should be firmly secured, and have a wide base to ensure steadiness in working. In cases where brackets may project some distance from the walls or other attachments, or in the case of hangers where they are placed much below the point of fixing, they should be firmly stayed to prevent vibration.

Pulleys should be bored and keyed on the shaft by a *sunk* key; hollow keys should never be used, they should be turned in the rim and edges; in the case of fast or loose pulleys, the loose ones should be bushed with gun-metal and worked against a loose collar fastened to the shaft by a *sunk set screw*. The diameter of the pullies should be ample to give a good grip to the belt, and in calculating the proportionate diameters to get the required speed, allowance should be made for the slip of the belt, especially in the case of damp places.

Tooth-wheels, both spur and bevel, should work with wood and iron teeth; the latter in all cases should be the driver; the iron teeth should be pitched and trimmed and turned on the face and edges. The wood teeth in the mortise wheels should be made of the best well-seasoned hornbeam, the face and edges of the wheel being turned.

Sliding Clutches should be provided, when wheels have to be thrown in and out of gear, with proper levers, quadrants, and safety pins; the nogs of the clutches should be made slightly taper and rounded at the nose to allow them to slip in easily and be drawn up tight. The levers should be made fork shape and be fitted with gun-metal rubbers on pins.

Cone Clutches are sometimes necessary to drive certain machines; they should be of ample diameter and be provided with strong levers, &c., of the same description as named above, to throw in and out of gear. In the cases of sack tackle, also for chain or rope barrels for hoists, &c., two cones should be used —one being placed at each end of the barrel.

Footsteps are necessary for vertical shafts; they should be fitted with gun-metal bushes, and be provided with concave discs of steel at the toe of the shaft, which is always reduced in diameter at this part. Proper provision must be made for oiling frequently; the author uses a special oil box, where the shaft always runs in a well of oil.

Couplings to join each length of shafting should be of the flanged type, faced, and the holes drilled and bolted together with turned bolts; the couplings should be countersunk one into the other, and be made true in the lathe after they are keyed on the shaft. The shafts should not be reduced in diameter in the couplings.

Transmitting Motion.

Leather Bands are usually considered the best means to transmit motion from the engine to the shafting, and from thence to the various machines to be driven.

Belting should be of good oil-dressed leather of the best quality, well stretched, and of ample width in proportion to the work to be done; the belts should not be laced up too tight. The distance between the centre of the driving shaft and the shaft in the machine to be driven should not be less than 8 to 9 feet.

Rope Gear is sometimes used as the main driver from the engine; several ropes are run off the pulley on the crank shaft which has a number of grooves turned in the rim; in the case of high speeds, the motion is taken direct from the rim of the fly-wheel. The ropes should be as long as possible and not put on too tight; they must be protected from grease, also from all vapour and damp.

Tooth-wheel Gear is advisable in many instances, especially where the shafting passes through places where steam or vapour of any kind is present. The *pinion* wheel both in spur and bevil gear should never be less than 6 inches to 8 inches diameter—this will of course depend upon the diameter of the shaft they are keyed to. Tooth gear must always be employed in transmitting motion at right angles, also when the shafts are running at acute angles. To take in and out of gear, the *wheels should not be shifted on the shaft*, but sliding clutches used as before described.

Pulley Gear.—The pulleys must be made 1 inch wider than the driving belt; as a rule one key is sufficient to fix them to the shaft, but when they are of large diameter, two should be employed; set screws should never be used. The width of the boss of a pulley must be made in proportion to the width of the rim; the boss should not be cored out, but should fit throughout the length of the hole.

Chain Gear is sometimes used when the motion has to be transmitted through wet places, or in the open air. The chain wheels in this case should be made with teeth on the rim, and the chain with square links, attached by flat iron S clips riveted at the centre; they should be made of wrought iron, and perfectly true to pitch. It is not advisable to use the chains in long lengths on account of their weight; in such cases it is better to use counter-shafts, and drive from one to the other.

Guards for Wheels.—Belts should be boxed in to prevent accident; they should be constructed to allow them to be taken down when necessary to make repairs ; as a rule they are best made of sheet iron. Vertical belts passing through the floor should be protected by wood guards or boxes of about 5 feet 6 inches high from the floor.

Oiling Machinery and Gear.—It should be the special duty of one or more men to oil all the shafting machinery and gear at stated periods, and to examine the straps and tooth-wheel gear, &c., to ensure that everything is in proper working order. The oil from the bearings should be caught in cups or receivers, and used for any rough purpose, but not for oiling the machinery. Mineral oil should be used; neither animal nor vegetable oils are suitable for the purpose.

Calculating Speeds, &c.—Allowance must be made for high speed machines for the slip of the belts; and for width of belts a good margin must be allowed, especially when they are exposed to damp or vapour or are in a greasy place.

Belts to Machines.—The length of belts necessary to drive machines mainly depends upon the speed and power required. As a rule, the distance between centres of shafts should not be less than 8 feet 6 inches to 9 feet. All fast-running belts should be entirely closed in to prevent accident. Roller guides to belts should be avoided wherever possible as they increase the wear of the belt.

Machines should be placed upon good foundations and be well fixed ; facilities should be provided for safely oiling each machine. When not in use, the bright parts should be oiled over to protect them from rust. All parts where oil is required should be supplied with lubricators, the caps of all bearings should have check nuts ; all tooth or chain wheels should be covered with an iron guard, provided with hinged doors to open to examine and oil when necessary; the doors should be fitted with locks.

Travellers are usually considered part of the equipment of the driving gear of a factory ; it may, therefore, be stated, they can be driven by shafting or rope gear, or direct by steam cylinders attached to a crab on the traveller. For outdoor works the boiler as well as the engine is often carried on the traveller frame. The details of these machines vary considerably according to the weights to be raised and other special considerations. It would be beyond the scope of this book to enter into the detail necessary to describe the various types. Travellers are now worked successfully by electric motors, and give much satisfaction ; these, however, can only be used where electric power is locally obtainable. In places where travellers are required to lift materials, &c., in and out of the machines the belt gear must be arranged to work clear.

General Observations.—In the above particulars for shafting, machinery and gear, only leading details have been given—sufficient for the intended purpose. The calculations for speeds, strength of shafting, and wheels are sometimes rather complicated ; in such cases they should be carried out by professional men. The proper management of a mill requires great care and special experience. It will always be found the most economical way to lay down all the plant and machinery of good quality; efficient working is not only ensured, but expense for wear and tear saved.

In many cases the steam cylinder can be attached direct to the machine, and run only when it is required. The author introduced this system many years ago, and in practice has found it work successfully and economically.

SUNDRY RULES AND DATA.

A few simple rules are given to assist proprietors and managers of mills and factories to enable them to state what they require sufficiently near the mark to prevent any great difference in the tenders, when they are inviting prices from several firms. It must be understood, these are only intended to apply to simple cases—it being assumed that professional assistance will be obtained in those more important.

Rule for Speeds of Wheels.

Multiply the diameter of the driver by its speed, and divide by speed of driven = the diameter. Thus: Driver 60 revolutions, with 36-inch pulley. Required the size of pulley on a shaft to be driven at 120 revolutions.

$$\frac{60 \times 36}{120} = 18 \text{ in.}$$

The same rule applies to Tooth wheels—the diameter must be taken at the pitch line of the teeth.

Rule for Width of Belts.

$$\frac{33{,}000 \times \text{H.P.}}{50 \text{ lb.} \times \text{velocity in ft. per minute}} = \text{width of belt.}$$

Rule for Spur Wheels.

$$H = \sqrt{D \times R} \times p^2 \times W \times M\ (\cdot 043)$$

in which :—

H = Nominal horse-power.
M = Constant ·043.
p = Pitch in inches.
w = width „
R = revolutions per minute.
D = diameter of wheel at pitch line.

Rule for Wrought Iron Shafting.

$$D = \frac{\sqrt[3]{65\ H}}{N}$$

D = area in inches.
H = I.H.P. to be transmitted.
N = revolutions per minute.

For prime movers,

$$D = \frac{\sqrt{83\ H}}{N}.$$

The above rules must be taken as approximate and simply as a guide to proportion the sizes ; judgment must be used to apply them to particular cases.

Approximate Rule for Boilers.

The Length should be $3\frac{3}{4}$ to 4 times the diameter.

The diameter of internal flues or tubes in Cornish and Lancashire boilers must not exceed in the former one half the diameter of the shell, and in the latter ·39 to ·4 diameter of the shell.

Data for Compound and Condensing Engines.

Condensing water required, $1\frac{1}{2}$ to 2 gallons per I.H.P. per minute, up to say 15 I.H.P., and for large engines, 1 gallon per I.H.P. per minute. The *inlet* temperature at say 55° F. When surface condensers are used, such as are designed and made by Messrs. James Simpson & Co., Limited, the quantity may be reduced to ·091 gallons per I.H.P.

Steam used in Engines.—15 to 22 lb. per I.H.P. per hour in compound engines, and in condensing engines about 22 to 24 lb. per I.H.P. per hour.

Cost of Working.

For engines and boilers for Mill and Factory purposes, for H.P. engines the cost is about 10*s*. to 11*s*. per actual H.P. per week of 60 hours; this includes all expenses — coal, oil, engine driver, repairs, interest on capital outlay, and sinking fund.

In large engines doing heavy pumping and with constant work of 24 hours per day, it may be taken at 12*l*. per year; this includes all cost of working *exclusive* of interest on capital outlay.

Coal consumed in different types of Engines.

	Per I.H.P.
Condensing engine, steam jacketed	= 2·26 lb.
Compound (beam) engine, pumping water	= 1·76 „
Compound (beam) mill engine	= 2·02 „
„ horizontal "Tandem" mill engine	= 2·09 „
Cornish beam (pumping)	= 2·44 „
Worthington engine (pumping).. ..	= 1·74 „

Data for Gas Engines.

Consumption of gas in Tonkin's patent engine, with a 7-inch diameter × 12-inch stroke cylinder, running at 160 revolutions per minute, and giving 6 I.H.P. = 21·3 cubic feet of gas per hour.

Average cost of working in the best type of engines may be taken for a 6 I.H.P. engine running 10 hours per day, with gas at 3*s.* 2*d.* per 1000 cubic feet, at about 3*s.* 4*d.* to 3*s.* 6*d.* per day, 21*s.* per week, and about 54*l.* per year of 52 weeks = 9*l.* per I.H.P.

Rule for Water in Pipes.

Contents of Pipes.—Square diameter of pipes in inches = weight of water in lb. per yard; shift the decimal point to left hand = gallons per yard. *Speed of water in pipes* from pumps should not exceed 2½ feet per second; when this speed is exceeded, much loss occurs through friction.

Rule for Water Pressure and Pumping.

Any area 33 feet high = column of mercury 30 inches high. Each 2·3 feet in height = 1 lb. pressure per square inch.

Area of pump valves for three-throw pumps = ·52 area of the pump barrel.

Friction and Slip in Pumping.—Allow 20 per cent. The pipes must not have any sharp angles; all bends must be easy.

Cost of Pumping Water for Mill and Factory Purposes.

To raise 1000 gallons to a height of 100 ft., by three-throw pumps—taking coals at 12*s.* ton = 4*d.*; this includes all expenses, including interest on capital outlay. The cost of pumping large quantities by special pumping engines, doing regular and constant work, is much less for the same quantity the same height—it may be taken in such cases it is as low as from ·19*d.* to 1*d.*

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