DBOOK
R
STEAM USERS

RULES FOR ENGINE DRIVERS
AND BOILER ATTENDANTS

M. POWIS BALE

627

195

RULES FOR ENGINE DRIVERS

&c.

A HANDBOOK

FOR

STEAM USERS

BEING

RULES FOR ENGINE DRIVERS AND BOILER ATTENDANTS

WITH NOTES ON

STEAM ENGINE AND BOILER MANAGEMENT AND STEAM BOILER EXPLOSIONS

BY

M. POWIS BALE, M.INST.C.E., M.I.MECH.E.

AUTHOR OF 'WOOD-WORKING MACHINERY' 'STONE-WORKING MACHINERY' 'PUMPS AND PUMPING' 'GAS AND OIL ENGINE MANAGEMENT' ETC.

NEW IMPRESSION

LONGMANS, GREEN, AND CO.
39 PATERNOSTER ROW, LONDON
FOURTH AVENUE & 30TH STREET, NEW YORK
BOMBAY, CALCUTTA, AND MADRAS
1915

BIBLIOGRAPHICAL NOTE.

First printed October 1887. *Reprinted December* 1887. *Second Edition March* 1890; *Third Edition December* 1891. *Reprinted March* 1894. *Fourth Edition September* 1898. *Reprinted November* 1900. *Fifth Edition August* 1906; *Sixth Edition September* 1909. *Reprinted May* 1915.

PREFACE

TO

THE SIXTH EDITION.

It is a matter of gratification to the Author that it has been found necessary to issue a sixth edition of this little book. Although during recent years no very startling innovations have been introduced into steam engines and boilers for land purposes, considerable progress has been made in improving and simplifying the various working details and in operating them on what may be termed more scientific lines.

The tendency is still in favour of higher pressures and multiple expansions; forced draught, steam superheating, mechanical stoking, and forced lubrication have also made considerable headway. The Author has taken the opportunity of adding some additional notes on 'The Working of Corliss and Trip Valve Engines,' on 'Forced Draught,' 'The Fixing of Lancashire and Cornish Boilers,' and 'Steam Superheating.'

15 Sutton Court Road, Chiswick,
September 1909.

PREFACE

TO

THE FIRST EDITION.

SOME YEARS AGO the Author published—chiefly for the use of his clients—a Chart of Rules for Engine-drivers to hang in engine-rooms. This has had a considerable circulation, proving that something of the kind was needed. Within the limits of a chart, however, it was impossible to include many things that might be of service to steam-users. The Author has therefore revised and added to these rules in the following pages, and embodied with them chapters on steam engine and boiler management, and steam-boiler explosions. The matter has been condensed as much as possible, and arranged in the form of paragraphs for easy reference.

The Author has for many years urged the necessity of a compulsory system of boiler inspection, and of granting certificates of competency to those having boilers under their charge, and his opinions in this respect have undergone no change—in fact, have rather been strengthened than otherwise. There is little doubt that many disastrous explosions have been clearly traced either to the gross ignorance of the attendants or the criminal carelessness of the owners. With an adequate system of compulsory inspection, the writer is of opinion we should hear much less of these 'accidents.'

APPOLD STREET, LONDON, E.C.
October 1887.

CONTENTS.

A

HANDBOOK FOR STEAM USERS.

INTRODUCTORY.

SELECTION OF AN ENGINE AND BOILER.

It need hardly be said that the selection of an engine and boiler of a type exactly adapted to the nature of the duty it has to perform is a matter of critical importance to its satisfactory and economical working, and unless this selection is judiciously carried out, heavy loss and annoyance may result. No boiler or engine can be pronounced as the *best* for all duties, and each separate case should therefore be judged entirely on its merits and the surrounding circumstances. As these must of necessity vary largely, we cannot do more here than give a few general hints. An untechnical user would do well to take the advice of a competent engineer before deciding for himself. Passing first to the boiler, what is required is a steam generator which combines strength and durability with economy in working. Of late years the employment of higher pressures of steam has come into vogue, consequently the tendency has been to introduce the use of steel instead of iron, and otherwise improve the methods of manufacture.

In selecting a boiler, of whatever type, the chief points to consider are—(1) the quality of the feed-water, (2) the quality of the fuel, (3) the cost of the fuel. If the feed-water and fuel are bad, a simple form of boiler, such as the Cornish or Lancashire, is to be preferred, as they can be readily cleaned and repaired, and fuel of inferior quality may be used. Should, however, the fuel be expensive, it would pay to purify the water instead, and use a tubular or perhaps a water-tube boiler in place of Cornish or Lancashire; in fact, bad feed-water will pay for purifying in all cases. If the feed-water and fuel are of good quality, and the latter expensive, tubular boilers can be recommended, as they will generate steam more rapidly than plain boilers, and can be safely worked at a higher pressure. In the case of vertical tubular boilers, the author prefers those arranged with a vertical shell and horizontal flue-tubes, instead of ordinary vertical tubes, as they may be easily swept and repaired, and are not so readily burnt out.

Water-tube boilers have been introduced of late years, and it is claimed for them that they are both safe and economical; on the other hand, there appears to be little doubt that some of them produce wetter steam than a good Lancashire boiler, and, having many joints and caps, are more troublesome to keep in order.

Where a large amount of boiler power is required, it will be found greater economy to employ a few large boilers, built to withstand as high a pressure as may be safely used, in preference to a greater number of smaller boilers, as, taking the units of power developed, they are less in first cost, occupy less space, are less costly to fire, and, having fewer joints and parts, can be maintained with greater economy.

In selecting a boiler, a full detailed specification of sizes, materials, workmanship, and fittings should in all cases be obtained from the manufacturer, with the brands of the boiler plates stated, and should these not be of well-established repute, a guarantee as to the tensile strength, ductility, and elasticity of the plates employed should be requested.

The boiler should be tested by hydraulic pressure to double the working pressure before leaving the works.

Ample boiler power should in all cases be provided, and the steam be conveyed to engine as hot and dry as possible (see pp. 37, 43).

In selecting an engine the chief points to be borne in mind are—(1) the nature of the work it has to do, (2) the speed and power required, (3) the cost of fuel, and (4) if under skilled management. For rough work, where fuel is plentiful and possibly the management unskilled, a plain slide-valve engine would probably suit better than a first-class one with automatic expansion, delicate governor-gear, &c., the loss of fuel being partly compensated for by the greater freedom from breakdowns and consequent repairs. On the other hand, in establishments where large power is required and skilled management is attainable, the most advanced form of engine is in the end by far the cheapest. In cases where fuel is dear, a good compound condensing engine can be used with advantage; but it cannot be too often repeated that where extreme economy is required a skilled engine driver is an absolute necessity. Again, where great regularity of speed is required, as in electric lighting, flour milling, printing, textile manufacture, &c., an engine of the very best class, fitted with sensitive governor-gear, is a necessity. In point of fact, the various details of engines, such as stroke, speed, governing, &c., should be arranged and modified to suit the duty the engine has to perform; in a saw-mill, for instance, where the variations in load are sudden and severe, a long stroke engine with powerful governor-gear is to be preferred to a short stroke high-speed engine with delicate gear, although I have more than once seen this latter type employed for this duty. If engines with a high piston speed are employed, it is important that the momentum of the reciprocating parts be balanced so as to relieve the shaft, &c.,

from excessive shock. The bearing surfaces should be longer and of greater area than in slower running engines, and the workmanship must be of the first order or they will be found to deteriorate rapidly. If the steam pressure by which an engine is worked would be likely to vary considerably, and the load likewise vary, to secure steady and even running the engine should be fitted with gear having a considerable range of cut-off combined with a powerful and sensitive governor. Whatever type of engine be selected, a full detailed specification, giving sizes and materials, should be obtained from the maker, with his guarantee as to brake horse-power the engine will give out at a certain steam pressure, and that it will work at its full speed and power without excessive vibration. See that the bedplate and frame and working details of the engine are of ample strength, also that the cylinder has sufficient metal to allow of reboring several times, that the steam passages are short, that the sliding and bearing surfaces are ample, and that they are adjustable for wear. Do not be persuaded into purchasing a low-priced engine or boiler under any circumstances, as you may rest assured that it is impossible to purchase a first-class equipment at the price of a common one. The loss sustained in a day by using a poor engine and boiler may not be great, but this multiplied by a series of years may amount to an enormous sum, in fact, in some cases enough to buy a first-class plant several times over. In giving out a contract be assured that the contractor is one of good repute and is possessed of the necessary skill and appliances for turning out work of the best class.

Having secured a suitable engine and boiler, we now pass to :—

RULES

FOR

ENGINE DRIVERS AND BOILER ATTENDANTS.

CHAPTER I.

RULES FOR ENGINE DRIVERS AND BOILER ATTENDANTS.

1. **Filling the Boiler.**—Fill the boiler with water till it rises to the mark on the gauge which shows the water line. If there is no water line marked fill till the gauge glass is about three-quarters full.

2. **Examine Water-gauge and Test-cocks.**—Open all the water-gauge and test-cocks, and see that they are in order. If the water does not enter the gauge-glass freely, it must be unscrewed and a piece of wire passed through the openings into the boiler.

3. **Cleaning Tubes &c.**—Remove all soot from the tubes and clear the fire-bars and ash-pit of clinkers and ashes. If the flues are dirty, have them swept.

4. **Lighting the Fire.**—Light the fire, which should be kept bright and even, and of a thickness of about 4 inches to 6 inches in tubular boilers, and from 9 inches to 12 inches in Cornish or Lancashire boilers, except when there is a surplus of steam, when a thicker fire may be used. The

thickness of the fire should be regulated by the nature of the fuel. Should the draught be bad from dampness, direction of wind, or other cause, a temporary artificial draught may be made by lighting some shavings in the smoke-box or chimney.

5 **Examine Safety-valves.**—As the fire burns up examine the safety-valve and *see that it moves freely in its seat.* Examine float, or low-water alarum if one is fitted.

6. **Lubrication &c.**—Fill the lubricators. A little fine-powdered plumbago or asbestos may be added with advantage, especially to the cylinder lubricator. The use of the best quality of oil or grease is to be recommended. What is required is a neutral grease that will not develop free or fatty acids under the action of steam. Its melting-point should be low, so that it will liquefy with a small amount of heat, and yet it should retain sufficient body that it will not readily run from the bearing surfaces. Lubricate piston-rod and guides. Examine eccentric and see that the key is tight and the lead of the valve has not been accidentally altered.

7. **Examine the Bearings.**—Examine systematically and screw up the bearings of the engine, not too tight ; this is best done, if required, immediately after finishing work for the day, as they are then expanded from the friction of working and are in their running condition. If bearings are tightened in the morning before commencing work, which is usually the plan, they are cold and therefore contracted. If a bearing get hot, cool with water and scrape off all scored or rough places ; if it knock in working let the faces of the bearing be slightly closer together. Lubricate well with a mixture of grease or oil and powdered plumbago, say 3 of grease to 1 of plumbago. If the bearing be large and subject to great strain or pressure the proportion of plumbago may be increased. Replenish all lubricators

before starting work, and guard all bearings as much as possible from dust. If there is undue friction on the bearings particles of metal will be found in the oil after using if it is spread on white paper.

8. **Raise Steam slowly.**—Always raise steam *slowly* and avoid forcing the fire, as this causes uneven expansion and strains and damages the seams and boiler plates. Keep an even pressure of steam, but not one that has to blow to waste through the safety-valve.

9. **Regular admission of Feed-water.**—Hot feed-water is in every way to be preferred to cold ; but if cold is used, do not admit it into the boiler in large quantities at a time. Keep the pump working *regularly*, but with the admission valve only partly open. We recommend the use of a feed-water heater, but if one is not fitted, direct the exhaust steam into the water tank, say a quarter of an hour after starting, as by that time any accumulated grease from the cylinder may have blown away.

10. **Examine height of Water in Boiler.**—*Examine height of water frequently* during the day, and try gauge and test cocks and float. Blow-out and scum taps should be opened once a day at least, oftener if the water is bad. Be sure that the float is acting properly, as it is apt to stick, especially if of very light construction. The water level in Cornish or Lancashire boilers above the surface of the flue should never be below 4 inches in depth under any circumstances, and a working level of about 9 inches will generally be found most suitable. In finishing work at night leave a full supply of water, in case of leakage or frost.

11. **Starting the Engine.**—Supposing steam to be up to the working pressure, the safety-valve having been tested at intermediate points, turn the fly-wheel of the engine till

the crank shaft is at half-centre. Before starting let the engine cylinder thoroughly warm; this is especially advisable with large engines or in frosty weather. Now open the cylinder cocks and turn on the starting lever or valve *gradually* to about one-third of its traverse. Steam now enters the cylinder and the engine is set in motion. When no more water is expelled from the cylinder close the cocks. See that there is no leakage of steam from the piston-rod packings or any of the joints. Allow the bearings of a new engine to be a little slack for a time. Never start or stop an engine suddenly.

12. **Surplus of Steam.**—When there is a surplus of steam close the damper, rake the fire-bars so as to admit the air from below, open the ash-pan lid, if there is one, and keep the furnace door closed. (N.B. The author recommends wherever possible the use of a damper worked by steam automatically, as it is certain in its action and independent of the boiler attendant. It can be arranged to act at any desired pressure of steam, and effects an appreciable saving in fuel. It is important, whatever form of automatic damper is used, that it be arranged with a sensitive action. This may be secured by hanging the damper on a steel-pointed screw-pin, and making the working parts with steel centres and V edges. This will allow the damper to open or close with rapidity when the desired pressure of steam is reached. Where the work varies very much automatic expansion gear should be fitted.)

13. **Testing Safety-valves and Pressure-gauges.** *Test the safety-valve at least twice a day*; if about one-eighth to a quarter of an inch of space is shown between the valve and its seat for the escape of steam, this is usually sufficient if the valve is of proper area for the boiler, but some valves are arranged to lift less than this. Pressure-

gauges should also be occasionally tested by shutting off the steam and letting the pointer run back to zero ; for this purpose the cock to the gauge should be arranged to open to the atmosphere when shut off from the boiler. Check also the safety-valve against the pressure-gauge by altering the former to blow off at whatever pressure is at that time shown on the pressure-gauge. If they do not agree have the gauge tested by a standard one. See that the figures on the pressure-gauge are large and plainly marked, so that they may easily be read at some distance away. It is also best to distinguish the average or safe-working pressure of the boiler by a red line on the gauge ; this can readily be reduced as the boiler deteriorates. If the pressure-gauge shows the blowing-off point and the safety-valve is found to be stuck or inoperative from any cause, start the feed-pump, close the damper, and open the furnace door. Start the engine, should it be standing, and let the fire out, or draw it when the pressure is reduced. *Never under any circumstances wedge down or overweight a safety-valve*, and 'wire drawing' the steam should not be resorted to. Should the valve leak at all, have it re-ground at once and made perfectly steam-tight.

14. **How to Test the Pump.**—*Test the pump occasionally* by opening the waste-tap ; if no water is expelled the pump is not working, either from there not being a vacuum, the packing or joints being out of order, the valves choked with dirt, or the pump hot. Before taking it to pieces place your hand tightly on the end of the waste-pipe, allowing the air to be discharged from the pump by the inward stroke of the plunger, but not allowing any air to re-enter during the outward stroke. If this has the desired effect in setting the pump to work, close the waste-tap and the water will be forced into the boiler. If the pump gets hot pour cold water on it. If hot water continually issues

from the waste-cock, the probability is *the check-valve nearest the boiler is choked.* In this case the steam must be blown off and the fire put out, the valve-box cover must be taken off, and the dirt or obstruction that prevents the valve acting removed. If the suction or delivery valves are choked hot water will not pass through the waste-cock; these valves may be examined when the engine is working, but should the defect not even then be discovered, the suction valves, delivery valves, and the packing of the plunger must be examined and the packing renewed, as the pump is probably drawing air; screw up and clean the union nut of the suction-pipe, and make another trial. Occasionally a valve that has stuck may be released by a few sharp blows of a hammer on the outside of the clack cover. If a pump plunger is worn it will not act, at any rate satisfactorily, and should be seen to. In case it is necessary to take the pump to pieces, should there be no check-valve fitted or it be choked, be sure that the water stop-valve is closed or the boiler may be drained of water and an accident occur. If a valve has too much lift it is apt to stick, and should, therefore, be adjusted periodically as it wears. Feed-pipes should in all cases be of ample size, owing to their liability to fur up. Bends in the suction or delivery pipes should be avoided. Take every precaution to prevent sand or grit getting into the feed-water. (See page 22.)

15. **In Case of Low Water.**—In case of low water—that is, where none shows in the gauge-glass or lower test-cock—*draw the fire immediately*, but, should the furnace crown be red-hot, cover the fire with earth or wet ashes so as to smother it. Close the damper and ash-pit door and open the furnace door. If the boiler is very hot and the heat is likely to be much intensified by drawing the fires, it

would be well to *smother them instead of drawing*, but judgment should be used, as no fixed rule can be laid down. If a little water is shown by the lower test-cock, the feed may be turned on. (The Manchester Steam Users Association say in this connection : 'Shortness of water generally arises from neglect of the boiler attendant, and ought not to occur. It is by no means easy to give precise instructions as to what should be done to put things right when shortness of water has occurred, so as to meet every case. Drawing the fires when the water is out of sight must always be a matter of more or less risk, as there is a difficulty in determining how far and for how long a time the furnace crowns have been laid bare. If it is known that the water has only just passed out of sight, say from the sticking fast of the blow-out tap when attempting to shut it, the fires may be drawn with safety. But if an empty gauge-glass has been mistaken for a full one, and the boiler has been worked on in this state for some time, the case will be different. Again, there would be more risk in drawing the fires from a plain furnace tube, or from one made of ordinary plates, than from one strengthened with encircling rings and made of ductile steel or of iron equal to Lowmoor or Bowling. Thus it will be seen it is difficult to give precise instructions to suit all circumstances. A fire may be safely drawn in one case and not in another.')

16. **Priming.**—In case of priming, close the throttle-valve for a short time, find the true level of the water, and open the cylinder-cocks. If the water level is correct, blow off a little occasionally and add fresh water, but not too much at a time. Check the draught to the boiler also, and damp the fire somewhat. See that the feed-water is not dirty or greasy. In boilers where the steam space is small, great regularity of firing and water-supply is necessary. If the

priming is violent, stop the engine. Open the cylinder-cocks occasionally. Some of the compounds sold to remove incrustation will cause priming. Priming may also be caused by bad circulation, by an excess of steam being drawn from the boiler, or by the introduction of oatmeal or similar substances with the object of stopping leaks. In case of violent priming, the gauge-cocks will discharge a mixture of steam and water instead of plain water. It should not be attempted to stop priming by the introduction of oils, as is sometimes done, as most of these develop fatty acids, which are often highly injurious to the boiler, and by mixing with the lime or other incrustation prevent a proper contact of the water with the boiler plates ; there is therefore a much greater tendency to burn.

17. **Examine and Test Steam-exhaust.**—An experienced and careful attendant can gather no little as to the working condition of his engine by attentively listening to the pulsation of the steam-exhaust. If the piston, slide-valve, and passages are in good order, the sound of the exhaust will be regular and decisive. If the piston is out of order, or the rings broken or worn, the pulsation will be prolonged, accompanied by a rumbling, groaning noise. If the pulsation is prolonged, with a wheezing noise, probably something is wrong with the slide-valve, and it may require adjusting or rebedding. In either of these cases steam is wasting past the piston or slide-valve and should receive immediate attention. To test for a leaky piston put engine on dead centre and listen to the exhaust ; should there be an escape of steam the piston or rings require attention, or the cylinder may want reboring. The piston should be tried at both ends of the cylinder. If there is a simultaneous discharge of steam through the pet-cocks at both ends of the cylinder, you may be sure the piston is leaky. To test for

leaky slide-valve, place engine a little over half-stroke and turn on steam ; if there is a rush of steam through the exhaust the valve leaks. Steam may also escape directly into the exhaust-pipe through a leaky joint. A leaky piston may be caused through the engine being out of line.

18. **Firing the Boiler.**—Use good fuel if possible. Do not put coal on in large pieces, but break it to about the size of your fist. Do not put on a large quantity of fuel at one time, but fire little and often. If the fire burns unequally or into holes, level it and fill up the vacant spaces. If anything, the fire should be rather thinner in the centre than at the sides of the fire-box. Do not let the fire get low before a fresh supply of fuel is added ; keep the furnace door closed unless there is a surplus of steam. Be careful in regulating the draft in the fire-box or furnace to suit the fuel being consumed. We recommend, wherever possible, the use of an automatic steam damper. A good supply of air promotes combustion and tends to prevent smoke. In Cornish or Lancashire boilers, begin to charge the furnace at the bridge, and keep firing to within a few inches of the dead-plate. Excessive draught should be avoided, as the heat is carried rapidly away, and sufficient time is not given for the combustion of the various gases. Coke requires a more rapid draught than coal. The flame of the fire should never come in direct contact with the boiler plate above the water line. The flame should never be allowed to impinge constantly on one spot, either above or below the water line. The fire should never be collected in a heap in the middle of the grate, as it allows cold air to rise through the bars all round it, and strike against the boiler plates.

Keep ash-pit and fire-bars clean and free from clinkers and ashes. Do not slack the ashes in the pit, but remove them at once. If it is necessary to use wood as fuel, it should be dry and be reduced to pieces, say twelve inches long. For, say, the last half hour before finishing work do not put any more fuel on the fire, and raise the water level in the boiler, so that the boiler may cool down gradually. With some kind of coal it is necessary to clean the grate often to prevent the fire becoming choked with clinkers &c.; to clean the front part of the grate, push the fire well back and use the slicer and clinker hook freely; to clean the back of the grate, bring the fire forward and pull the clinkers over it. When this is finished, spread the fire evenly again and put on moderate supply of coal. The fire should not be allowed to burn too low before cleaning, or the steam pressure may drop considerably, or the fire go out. Before cleaning see that there is a good supply of water in the boiler, and partly close the dampers whilst cleaning. Remember that scale in the boiler and choked tubes often render it necessary to force the fire to make up the loss accruing therefrom. Fire as rapidly as may be, and do not keep the furnace door open longer than is necessary. Whenever possible the damper should be kept closed when the furnace door is open, and *vice versâ.* A bright incandescent fire will reflect a bright light into the ash-pit. If the ash-pit is dark, there is probably an accumulation of ashes or clinkers that require moving. A good fireman will see that no useful cinders are thrown away with the ashes. If a forced draught is used thicker fires than those already mentioned may be employed, but care should be taken that a forced draught is not used when the grate is partially uncovered, or leaky tubes or seams will soon be the result. (See page 78.)

19. **Prevention of Smoke.** — The prevention of smoke is very largely a matter of careful, regular, and even firing, and the admission of exactly the right quantity of air

into the fire-box. Furnaces constructed of ample area and cubic capacity will burn smoke better than those that are confined. A good supply of hot air admitted from the bridge of the furnace aids combustion. Use a furnace door through which the supply of air may be easily regulated, so as to spread, as it were, an even sheet of air over the surface of the fire. Alternate firing on each side of the furnace has a tendency to prevent smoke, but with most coals the author can recommend the following plan as a decidedly good and effective one for aiding combustion and preventing smoke. Supposing the fire to be in an incandescent state, and it is necessary to put on more fuel : instead of throwing the coal on in the usual way, push back the fire from the front part of the firegrate on to that behind, nearer the bridge, leaving the front of the grate bare. Now charge the front part of the fire-box with fresh coal ; this will gradually coke, and the various gases &c. which form smoke will be liberated at a slow rate and give time for the air passing up through the fire-bars to become heated and mingle with them, thus promoting tolerably perfect combustion. With this plan, with ordinary steam coal and tolerably open fire-bars, a sufficiency of air will pass up through the fire-bars in the front of the grate to consume the gases, and large volumes of smoke need never be made, as is the case when great quantities of fuel are thrown on to a hot fire. The reason of this is, that in this latter case, owing to the incandescent fire acting quickly on the coals, the combustible gases or hydro-carbon are so rapidly released that there is not a sufficiency of air admitted to the fire-box and heated fast enough for it to combine with and consume the liberated gases, hence the production of free carbon or smoke. This coking system of firing should be performed at regular intervals, and only moderate supplies of fuel be put on at one time.

In cases of urgency, smoke may be 'whitewashed' by turning the exhaust or a jet of steam into the base of the chimney-stack. Bear in mind a blue flame shows imperfect and a white one tolerably perfect combustion.

20. **Fire-bars.**—As fire-bars are burnt out renew them; do not wait till the whole set is worn out. Allow a good current of air to enter through the ash-pit and fire-bars, or the latter may become overheated—especially with some kinds of fuel—and burnt out. If the fire burns sluggish it may be from insufficiency of draught or the fire-bars may not be provided with sufficient air spaces, and these getting choked require constant attention to prevent the bars warping or burning. Keep the ash-pit and fire-bars clean and free from clinkers and ashes. Do not allow an accumulation of hot ashes in the ash pan or pit, as they have a tendency to twist the fire-bars. In some cases, with coal given to form much clinkers &c., rocking fire-bars may be used with advantage. Do not take more time than is necessary in cleaning bars, leave the damper open, and when the coal is pushed back do not let a fierce fire impinge against one place in the fire-box for any length of time. Hard steam coal requires less air space between the bars than a flaming bituminous coal. Never throw water into a warm fire-box to loosen ashes or clinkers by contraction. (See page 32.)

21. **Working Portable Engines &c.**—In the case of portable engines place the driving-wheel exactly in a line with the pulley of the machine to be driven. Fix the smoke-box slightly higher than the fire-box end. Wedge up the wheels and see that the engine does not rock in working. Always keep about two inches of water in the gauge-glass, and blow off occasionally through the glass to see that the ways are clear. Clean the boiler periodically right through, and if

the water is bad remove the hand-hole in the fire-box, and carefully remove all sediment over the fire. An accumulation of sediment is the chief reason for burnt boiler plates. On finishing work, a great deal of scum and dirt may be got rid of by blowing off at a low pressure, if possible, when the engine is being removed to a fresh job.

22. **Working Traction Engines.**—As regards the working of traction engines, the rules given above will apply equally well to these as to most other types of engines and boilers ; in addition, however, the driver of a traction engine should bear the following points in mind : 1. Keep a good supply of water in the tank. 2. Disconnect the traction gear, and start the engine under a moderate head of steam, say 25 lbs. pressure, to see that the pump and all the working parts are in order. 3. Carefully oil all bearings and grease the teeth of the various wheels. 4. For travelling, get steam up to about 75 lbs. pressure. 5. When going down a hill the gauge-glass should show 1 inch of water ; when going up, about 4 inches. 6. In going down hill, lock the hind wheels of any vehicle being drawn ; use the reversing lever, both for shutting off steam and for checking the momentum of the engine, by admitting steam to the reverse side of the pistons.

23. **Working Engines and Boilers in Frosty Weather.**—When working in frosty weather, the following additional precautions are advisable : 1. Close the tap between the boiler and the water-gauge glass when the boiler is stopped for the night, and let the water out of the glass. 2. Leave the cylinder-cocks open, to drain off the condensed water, also the jacket-cocks if the cylinder is jacketed. 3. Examine the pump and valves and supply pipes carefully before starting work ; if frozen, pour hot water

on them till the ice is thoroughly melted. 4. In very frosty weather have the fly-wheel of the engine barred or turned round by hand a few times, in case of ice being in the cylinder. 5. Thoroughly warm the cylinder before starting, carefully try the different cocks and pour hot water on them if stiff. 6. See to the cylinder and other lubrication. Kerosene mixed with oil will prevent it freezing. 7. Leave all drain-cocks in pipes &c. open ; the water in boiler may be prevented freezing by banking the fire.

24. **Blowing off or emptying Steam Boiler.**—If the boiler is emptied under pressure, a practice we do not usually recommend, the pressure should not exceed, say, 10 lbs. per square inch. It is better to let the damper be open and blow off through the safety-valve, at the same time adding fresh cold water to mix with that in boiler if early cooling is necessary. On no account throw cold water on hot plates ; the cooling should be gradual and general ; it is better not to let the water out of the boiler till the boiler plates and boiler seatings are cool. Never admit cold water when the boiler is empty and warm. One disadvantage of blowing off under pressure is that the boiler plates and brickwork, being left hot, have a tendency to harden any scale or incrustation that may be adhering to them. Before removing manhole or other covers lift the safety-valve and make sure there is no steam in the boiler ; neglect of this precaution has caused accidents.

25. **Cleaning the Boiler.**—To clean the boiler, remove all the covers of the manholes ; scrape, or if there is much hard incrustation, chip the interior surface, thoroughly loosening and removing all sediment and dirt. Pass a quantity of clean water through the manhole. Examine and clean all feed-water and other pipes periodically ;

remove and scrape fusible plug, and renew if necessary. Keep all flues or tubes thoroughly clean and free from soot, &c. Examine all cocks and fittings, and see that they are in order and free from leakage. Examine the flues and see that the boiler seatings are dry, and that there is no leakage either from the seams or from the roof. Tubular boiler tubes should be swept once a day, or twice if the fuel be bad. This can be readily done with a jet of steam.

26. **Engine and Boiler out of Use.**—When a boiler is out of use for a time it should be entirely emptied of water, carefully dried, and painted with an oxide paint inside and out. Several boxes of quicklime for absorbing moisture should be put inside the boiler, and if on inspection it is found much slaked it should be renewed. Coat the bright parts of the engine with a mixture of white lead and boiled tallow, say two pounds of the former, six pounds of the latter, or, if preferred, a mixture of boiled oil and turps may be used.

If an engine has been standing some time it should be thoroughly overhauled and cleaned over with paraffin to remove dirt, and well lubricated. Before starting, the engine should be well blown through with steam to warm the cylinder and try the joints, which may require renewing.

27. **Stopping Engine.** — In stopping the engine, turn off the steam *gradually* and not suddenly, as this latter practice has been known to start joints or split pipes from the shock arising from the sudden stoppage of the flow of steam. Unless a barring engine is used, care should be taken that large engines are not allowed to stop on the dead-centre, or they will give considerable trouble in being levered round by hand. Large establishments should be so arranged that instant communication can—in case of

accident—be made with the engine driver. An electrical apparatus is now in use by which the engine can be instantly stopped from any desired point.

28. **Banking Fires for the Night.**—Although there is some little danger attached to the practice of banking fires, in a series of boilers it saves a great amount of trouble, and is generally resorted to. The following precautions should, however, be observed: 1. Put the safety-valves to blow off at a low pressure, say 10 lbs. 2. Leave the furnace doors open. 3. Close the dampers and ash-pan lids or ash-pit doors. 4. See that each boiler has a full supply of water and the float is in order.

A good plan in banking is to partly clear the front of the fire-bars and push the fire into a gradual bank at the back, making it as solid and free from air spaces as may be; then cover with wet ashes and coal dust mixed, to a depth of, say, six inches. Arrange the admission of air so that there is just sufficient to keep the fire alight and nothing more. It may be added, that judicious banking of a fire is less injurious to a boiler than the constant lighting up and drawing the fire out, as the extremes of expansion and contraction are done away with. It is somewhat difficult and risky to attempt to bank fires in tubular boilers.

29. **A good Engine-driver and Boiler-attendant.** The greatest factor in the making of a clever engine-driver and boiler-attendant is *regularity*; a good man will keep up an even and regular supply of fire, water, and steam the whole day through, whilst a careless or inefficient man will have steam blowing off one hour and a pressure barely sufficient for the work the next. An incompetent attendant is dear at any price. To test accurately the performance of the engine under his charge, the skilled engine-driver should

be capable of working the indicator and taking diagrams; this work, however, I am afraid at present is relegated to those higher in authority, but there is no reason why a fairly educated man should not do it, as several plain and practical treatises are published on the subject.

CHAPTER II.

MANAGEMENT OF STEAM ENGINES AND BOILERS.

Boilers.

Boilers.—It need hardly be said that important factors in the safe and economical working of steam boilers are, (1) the proper fixing of the boiler, (2) its proper equipment with safety and other fittings. There is no doubt that large numbers of boilers are at work badly and improperly set, and equipped with inadequate and poorly made fittings, and with some of these improperly placed. The wonder is, under the present system of non-inspection, that more accidents of a serious character do not occur. I hope the time is not far distant when it will be compulsory that all boilers shall bear a full equipment of safety and other fittings, and that they shall be inspected thoroughly periodically by competent and unbiassed persons.

Low-water Floats and Alarums.—The ordinary old-fashioned float, if carefully made and balanced, is an extremely useful adjunct to the Cornish and Lancashire boilers. Care must be taken, however, that its action is sensitive, that the suspending wire is not allowed to oxidise, and that the float is made of sufficient weight to sink readily with the water. We have known several cases of floats failing to act through being made too light. The float should occasionally be tested to see that it indicates the depth of the water correctly; this can be done by holding the counterbalance weight in the hand, lifting the float out of the water and lowering it gently again, and marking exactly the point where it stops. Now force the float down into the water as far as it will go, and let it ascend gently ; if it stands exactly at the point already marked, it is correct. A dial showing various heights of water should in all cases be fitted.

The latest thing in low-water alarums consists of an electric battery placed on a wall near the boiler, and connected with a gong by negative and positive wires ; these wires run to the water-gauge and connect with a glass bulb filled with mercury. When the water falls below the point of attachment, the steam rushes into the space surrounding the mercury bulb, and the mercury expands. As it rises in the tube it comes in contact with a platinum wire, thus closing the circuit and ringing the alarum gong. When the water is pumped into the boiler, it forces the steam back, breaks the circuit, and puts the alarum into working order again. This idea, to say the least, is ingenious. The author has not, however, had an opportunity of practically testing it, but has been informed that its working is very successful. Low-water alarums acted on by the melting of a fusible disc are useful.

Another form of low-water alarum is obtained by means of an expansion tube ; this is so arranged that when the water is at its normal level the expansion tube is full of water, but should the water fall below its proper level the water falls out of the tube by gravitation, and steam takes its place. This steam heats the expansion tube, which causes a valve to lift and sound a whistle. It may be as well to say the expansion tube, being exposed to the atmosphere, remains comparatively cold until the steam is admitted. When water is admitted into the boiler and fills the expansion tube it is gradually cooled, and the whistle valve is allowed to close.

With the object of doing away with the stuffing-box of the ordinary float, and therefore with the chance of its sticking, a new arrangement of float, or, as it is called, a balance valve feed-water regulator, has recently been introduced and is worthy of notice. Instead of having a wheel weight and chain on the outside of the boiler in the ordinary way, the whole apparatus is placed inside the boiler, usually in the dome. At the delivery end of the pipe leading from the pump is a valve-box, made in two sections screwing together, and fitted with two discs or puppet valves, one of which is arranged to close an opening in the upper section, while the other closes an opening in the lower section. These valves are connected by a common stem, so that they virtually form but one balance valve, which opens downwards. Each valve is formed of wings or guides arranged to fit the opening, for the purpose of steadying and directing the double valve in its movement. The lower valve is connected by a central rod with an ordinary open float. As the water lowers, therefore, the valve will descend and permit the passage of steam through the outlet pipe to the pump or injector, or to a whistle, and when the water again reaches its normal level the valve will be closed by the float, to which steam is admitted to equalise the pressure and prevent collapse.

Safety-valves.—A considerable number of different forms of safety-valves, governed by weighted levers, springs, deadweights, &c., have been introduced. In the most advanced practice deadweight valves have of late been largely used, and they undoubtedly possess some advantages over the ordinary form of weighted lever valves. In the ordinary form of lever safety-valve, to allow all the steam it is capable of discharging to escape safely, it should lift from its seat a distance of one-fourth its diameter; but few, if any, valves can do this, consequently it has become the practice to fit valves of a much larger area and lip escape than is theoretically necessary. Various rules as to area have been adopted; that used by the Board of Trade is half a square inch per square foot of fire-grate area. These rules cannot, however, be considered arbitrary, as there is no doubt that the working steam-pressure should be an important factor in calculating the necessary safety-valve area, and that a considerably larger valve is necessary for low pressures than for high. Conical valves are to be preferred to flat-faced ones. The valve and its seat should be of the same metal—gun-metal is to be preferred, as it is less given to oxidation than iron—so that their expansion may be equal, for which allowance should be made. Stops should be fitted on the lever to prevent the weight being moved accidentally.

A considerable number of safety-valves, governed by spiral and other forms of springs, are in use, but these are giving way chiefly in favour of deadweight valves. Safety-valves governed by a thumb nut compressing a spiral spring are distinctly dangerous, especially when placed in careless or ignorant hands.

It may be occasionally necessary to ascertain at what pressure a lever safety-valve is weighted, and a skilled engine-driver should be capable of doing this. I therefore append a rule for that purpose:—

Rule.—Ascertain the length in inches from the fulcrum of the lever (the centre of its rotation) to the point which rests on the centre of the safety-valve, and also the length from the fulcrum to the point on which the ball-weight is hung. Then get the weight, in pounds, of the ball-weight; then multiply this by the length, in inches, of the lever from the fulcrum to the point where the ball-weight rests. Then ascertain the area of the valve in square inches, and multiply this by the distance in inches from the fulcrum to the point of the lever which rests on the valve ; and with the product of these divide the product of the former quantities—the ball-weight and lever. This will give the pressure of steam per square inch which the valve is set to.

Valves arranged to work with an iron spindle through the covers are objectionable, as they are apt to rust and stick fast ; and if sufficient clearance for expansion is given a leakage of steam usually occurs, which, being condensed, rapidly rusts the valve and its seat. Ball-seated valves are not so liable to stick as most forms, and some internal and deadweight ball-seated valves are now made which cannot be tampered with, and possess the advantages of extreme simplicity and sensitiveness ; and as there are no guides, joints, or levers, are much less liable to get out of order than ordinary valves.

Whatever form of valve is used, it is important that as the boiler deteriorates the weight on the valve—or, in other words, the blowing-off point—is reduced in proportion.

In Case of Safety-valve Sticking.—Should the safety-valve stick from any cause, and the pressure of steam be near the blowing-off point, (1) keep the engine running, and if steam is taken off for any other purpose open the valve ; (2) start the feed-pump ; (3) close the dampers ; (4) open the furnace door ; (5) if thought necessary, damp down or choke the fire with wet ashes.

Steam Boiler Feeding.—In working steam boilers a certain and constant supply of water is of very great importance. It should be as hot as can be forced into the boiler. In small powers the pump may be attached to and worked by the engine, but with large powers we prefer to have a separate pump of simple construction, such as the donkey pump, as, should the engine break down, a supply of water may still be kept up in the boilers. If a plunger pump is used, care must be taken that the plunger is a tight fit; if it is worn, the pump may be working without forcing any water into the boiler, and, should this not be detected, dangerously low water may be the result. Pumps for boiler feeding are best run at a moderate rate of speed, say a plunger speed of about 300 feet per minute. Several successful automatic self-feeding water supply apparatus are also now in use. If feed-water is drawn directly from a river, a strainer should in all cases be employed, as dirt or sand may be drawn into the pump and disable it. In large establishments, and to avoid the chance of being laid idle, in addition to the pump it is advisable to have a second feeder; for this purpose an injector may be used. The chief advantages of using an injector are that it may be worked without running the steam-engine, and the steam admitted to the injector is condensed, and re-enters the boiler, and from the absence of working parts the wear and tear is less than with a donkey pump. Injectors, however, should be carefully managed, or they may give some trouble.

In working injectors, which may be fixed horizontally or vertically, a continuous supply of dry steam is necessary. This should be regulated by a valve on the boiler or steam pipe. The water supply must be continuous, and should not be hotter than 135° Fahr. with low pressure, or 105° Fahr. with the highest pressures. Injectors may be fixed either above or below the water supply, and they will draw from 2 feet to 12 feet, according to size. An injector has one advantage over a pump—that is, it will usually stop forcing water before the pressure in a boiler becomes dangerous, owing to a jambed safety-valve or what not, whilst a pump will go on forcing water and raising the pressure till the boiler has to give way unless the valve is released. An injector will not work if allowed to get hot or any dirt to get in it; the suction-pipe should in all cases be fitted with a nozzle. Suction and delivery pipes should be kept as free from bends as possible, as the friction of the water through the pipes is considerably increased by them.

Injectors, like pumps, must be kept very clean, and all pipes and joints perfectly tight, or they will not work. It is advisable to fit injector and pump pipes with cocks for draining off waste water; these will be found particularly useful in case of frost. For automatically regulating the water supply to about one level in the boiler—an important factor in economical working—several plans have been introduced; one of the simplest with which we are acquainted consists in the arrangement of a small single-acting steam cylinder mounted on the feed-chest, and having the piston-rod connected to the feed-valve, which is kept closed by the downward pressure of a spring on the steam piston. A pipe connected to the cylinder leads to the steam space of the boiler; the lower end of this pipe is closed by a valve, the spindle of which is connected to a counter-balanced lever having a float suspended from one end. When the float sinks below a certain point, the steam valve opens and admits steam under the piston, which, being forced up, admits water into the boiler till the normal level is attained.

Sandy water should not be used as a feed-water, as it will rapidly cut the pump plunger to pieces and jamb the valves.

Feed-water Heaters and Filters.—There is little doubt that a very considerable economy is effected by using a good feed-water heater, as this [1] not only raises the water to a high temperature before it enters the boiler, and so saves fuel, but it also precipitates many of the impurities contained in it and prevents them entering the boiler, and,

[1] *Steam and Machinery Management*, M. Powis Bale.

in conjunction with a filter, water may be rendered in a great degree free from minerals and acids by heating to a high temperature and filtering whilst hot. Feed-water heaters have not been hitherto very largely used, but we take it, as skilled boiler management becomes more and more necessary on account of economy, they will be rapidly introduced. Complicated forms of heaters should be avoided. Heaters should be easily cleaned and examined, and any tubes employed should be so arranged that they have freedom to expand or contract, and have a rapid circulation. The tubes should by preference be made of solid drawn copper or brass, as they will be found more durable and less liable to leakage, corrosion, &c., than wrought iron. For large sizes cast iron may be used, but care must be taken that it is uniform in thickness and is sound. In one form of feed-water heater which is in successful use the water is heated to the precipitating-point, and a chemical separation of impurities takes place. In accomplishing this, exhaust steam is used up to 208° to 212° Fahr., after which the temperature is raised to the precipitating-point by means of a live steam coil. After the precipitation the water is filtered through wood, charcoal, or other suitable material, by which a mechanical separation of the impurities is effected; the purified water then passes out of the heater into the boiler. The heater may be cleaned by a jet of live steam from the boiler.

Whatever feed-water heater is employed, it is important that provision be made to prevent any back pressure on the engine; this can be done by fitting a relief valve so arranged that whenever the pressure of the exhaust exceeds that of the atmosphere to any appreciable extent, the valve opens a communication between the inlet and outlet. The author has known several cases of back pressure arising from the above cause which remained undetected for some time.

To ascertain if Feed-water contains Lime or Acid.—It will certainly pay all those who contemplate employing steam power, or who are troubled with incrustation, to have the feed-water properly analysed ; but as in the colonies and remote districts this may be a matter of some difficulty, the following tests may be of some service. In testing for lime, into a glass of the water drop a crystal or two of oxalic acid. If a precipitate takes place, and if another glass of the same water becomes milky on blowing air from the lungs into it through a quill, the presence of pure lime or barytes may be inferred. In testing for acid, take a piece of paper containing no sizing, and which has been previously stained with litmus, syrup of violets, or scrapings of radishes, and immerse it in the water to be examined. If the water becomes red, it contains acid. If a little lime-water be added to the same water and a precipitate takes place, it is carbonic acid. If dark blue paper, such as is wrapped round loaves of sugar, be converted to red, it contains a mineral acid. This latter is extremely deleterious to boilers. Litmus paper can be bought at any chemist's ready for use.

Incrustation in Steam Boilers.—Dr. Joseph Rogers, of Indiana, who has studied closely the question of incrustation in steam boilers, gives tannate of soda the preference over any other preparation with which he is acquainted for the chemical purification of the feed-water, and it is without doubt the principal ingredient of many of the boiler-cleansing fluids sold, about which the vendors profess to make a great secret. The action of tannate of soda may be described as follows : The tannates of lime and magnesia are insoluble in water ; hence when tannate of soda is present the carbonates of lime and magnesia present in the feed-water (and held in solution therein by the carbonic acid present in the water) are precipitated as they enter the boiler in the form of tannates of lime and magnesia. These compounds are not crystalline, pulverulent, and heavy like the carbonates, but light, flocculent, and amorphous, so that they do not subside in the boiler, but are held in suspension in the circulating water, gradually finding their way to the mud collected, from which they can be blown out as may be convenient. The soda of the decomposed tannate of soda appropriates the carbonic acid of the lime and magnesia, forming a bicarbonate of soda, which in turn decomposes the troublesome sulphate of lime, forming sulphate of soda, which remains in solution, while the carbonate of lime formed is decomposed, as above stated, into tannate by fresh portions of the tannate of soda present. The solvent action of the tannate upon hardened scale is slow, but when the boiler is once clear there is little doubt that it is a most excellent preventive, and, unlike other remedies used, it has no injurious effect upon the iron of the boiler.

Numerous other remedies have been used to prevent incrustation with varying success ; some of these we give herewith, but it must be understood we do not in any way guarantee their success. 1. Potatoes, $\frac{1}{50}$ of weight of water is said to prevent adherence of scale. 2. 12 parts salt, $2\frac{1}{2}$ caustic soda, $\frac{1}{8}$ extract of oak bark, $\frac{1}{2}$ potash. 3. Pieces of oak-wood suspended in boiler and renewed monthly. 4. 2 oz. muriate of ammonia in boiler twice a week. 5. A coating 3 parts of blacklead, 18 tallow, applied hot to the inside of the boiler every few weeks. 6. 12 lbs. of molasses fed into an 8 h.-p. boiler at intervals is said to have prevented incrustation for six months. 7. Mahogany or oak sawdust in small quantities. Use this with caution, as the tannic acid attracts iron. 8. Carbonate of soda. 9. Slippery elm bark. 10. Chloride of tin. 11. Spent tanner's bark. 12. Frequent blowing off.

Hard feed-water containing lime &c. may be softened to a very considerable degree by treating it with a mixture of lime and soda, allowing the precipitate to settle before the water is used. This will largely prevent incrustation (see also p. 72).

Water-gauges and Test-cocks.—Although the safety of a boiler depends to a certain extent on the water-gauge and other fittings, we often see a fairly well-made boiler equipped with poorly made cheap fittings. This may be all very well as regards extra profit for the boiler-maker, but it may become a matter of serious moment further on to the boiler-user. Poorly fitted cocks are much given to stick fast or leak, consequently boiler-attendants are liable to get into the habit of leaving them alone. To render them less liable to leak, and yet turn easily in the seats, asbestos packing has lately been introduced with very satisfactory results. Another recent introduction in connection with water-gauges is an automatic valve fitted just below the glass, and so arranged that should a glass break the valve immediately shuts off the rush of water from the boiler. The attendant is thus able to turn off the cocks and replace the glass without the risk of being scalded. One of these valves the author has recently tested with satisfactory results. The automatic valve is of simple construction, and can be lifted or taken out and cleaned as may be required. In the case of water containing much sediment this should be done at regular intervals.

Cornish and Lancashire boilers should be fitted with two water-gauges, as they act as a check on one another, and if one got choked, the other would show the proper water level, as they would in all probability never be choked at the same time. With the object of preventing the choking of gauges when very bad water is used, fittings are now made in which a valve with a blade fitted to the end of it is so arranged that every time the cocks are opened the blade clears the passage of sediment or any other obstruction that would prevent a true level of water being shown. To clean gauge-glasses themselves, make a solution of potash and water and apply it with woollen yarn twisted round a stick to make an easy fit.

Water Gauge-glass Fittings.—As gauge-glasses are given to break, especially in frosty weather, a small stock should be kept in hand cut to the right length, with the necessary india-rubber rings or washers for fitting them in. We prefer gauge-glasses made with white enamel backs, with a broad red line down them, instead of plain glass tubes, as the water level can be distinguished much more readily, especially in an uncertain light or at night. As regards the gauge-cocks, these are much to be preferred made solid with a union on the one side, instead of allowing the tap to go right through the fitting and be held in position by a back nut on the other side, as they are less liable to leak, and should they leak the water is obliged to come through the mouth of the taps. In the case of fittings with back nuts, should a leakage begin the attendant often tightens these up and gradually strips the thread. Asbestos-packed cocks can be recommended, and ebony-handled cocks are preferable to brass, as they do not get so hot. Test-cocks should be fitted with cleaning screws, as this often saves a good deal of trouble. Gauge-glasses may be cut to length either by filing round the glass with a three-square file or by scratching round the inside of the glass with a round file, having previously marked the outside at the length desired.

Should india-rubber washers not be to hand, the glass may be packed with hemp or string and red lead, but as this latter sets hard it is troublesome to remove. Be sure the glass is cut to the right length and does not overlap the passages into the boiler, or it will burst when the water is turned on. Let the glass warm a little from the heat of the boiler before it is used.

Fusible Plugs.—If kept in proper order fusible plugs are extremely useful and necessary fittings, and should be fitted to all steam boilers, as they not only give the alarm in case of low water, but help to put the fire out and so arrest further danger. The fusible plug should be fitted where the fire is hottest.

It has been found that the metal of most fusible plugs, if subjected to the continuous action of the water and heat of a steam boiler, becomes chemically changed and the fusing-point may be altered considerably. To prevent the water or steam coming in contact with the fusible metal, copper caps are often fitted, but we have recently inspected one issued by a boiler insurance company in which asbestos is used, and we must pronounce it in advance of anything we have yet seen for the purpose. In this plug a packing wad of asbestos is introduced between the water or steam and the fusible metal in such a way that any contact is prevented. The asbestos wad at the same time prevents the cooling action of the steam on the fusible metal, and therefore, in case of low water, the melting of the plug is facilitated. A lead washer is used to make a joint in the opening to the boiler. An advantage claimed for this form of plug is that partial fusion of the white metal is prevented, as the plug does not act till the whole of the metal is melted, when the pressure of the boiler forces out the lead washer and asbestos-packing wad, leaving a clear opening for the escape of the steam. This is an improvement, as in cases of partial fusing the rush of escaping steam stops at once any further fusing action.

Furnace Doors. — Large furnace doors are to be avoided, owing to the rush of cold air which takes place when firing; in some cases two small doors are preferable to one large. See that they fit close.

Scum cocks &c.—These are necessary and useful adjuncts to all boilers, more especially where the feed is bad, as a great deal of impurity may be got rid of through them.

Care should be taken that blow-off or sludge cocks are not allowed to stick. For blowing-off purposes we can recommend the use of a parallel slide-valve tap, as it will work at any pressure, does not require packing, and is self-cleaning.

Dampers.—All boilers should be fitted with some kind of damper, and, wherever possible, a damper automatically worked by steam is to be preferred to a slide damper worked by hand, as this latter is often neglected by the attendant, with a consequent loss of fuel. An automatic damper can be arranged to act and damp the fire at any desired pressure of steam. In addition to a damper in the chimney-stack, the ash-pan or ash-pit door should be arranged to damp also. In boilers without dampers the draught has to be checked by opening the furnace door, a practice not to be recommended, as the constant rush of cold air has a distinctly injurious and straining effect on the boiler. Some notes on working the damper and regulating the draught will be found elsewhere. In the case of boilers with bad or deficient chimney draught, or those using very inferior fuel, a steam jet blower can often be used with advantage; this is, perhaps, best arranged so as to force the air through the fire from below the grate. Leakage or broken masonry in the boiler flues will damage the draught considerably. Dampers and ash-pit doors should shut tight.

Fire-bars Warping &c.—One of the reasons for grate-bars warping is insufficiency of air space between the bars ; this should be arranged to suit the fuel burnt, as some coal requires much more air space than others. Another reason is that in many boilers the fire-bar bearers are fitted close up to the bridge and head-plate, consequently hot ashes and clinkers accumulate, having no place to escape. This may be obviated by putting the bearers a short distance from the end of the bars, so that the ashes &c. have room to escape into the pit. Long fire-bars warp more than short ones, and thick bars more than thin ones. The air spaces between the bars should be wider at the bottom of the bar than at the top, as this facilitates the admission of air and the escape of ashes. Air and water bars have their advocates, and doubtless possess some advantages ; but the water bar, although long known, has made little progress, probably owing to the cost of maintenance and the danger arising should they burn out or rupture suddenly. In burning anthracite coal, water hearths are used to some extent. A very great variety of fire-bars have been introduced, but I cannot discuss their merits or demerits here ; it will be sufficient to say that good fire-bars should give ample air space, so that the amount of oxygen necessary for complete combustion is readily distributed through the fire, and at the same time should not be given to warp and should be easily cleaned or renewed.

Condensed Steam in Pipes &c.—There are two ways of effectively getting rid of this, viz. by using a steam trap for getting rid of the water after it is made, or by the use of a steam separator which acts directly on the steam itself and relieves it of the water. To prevent radiation and reduce the amount of condensation to a minimum, all steam pipes should in the first place be carefully covered with some good non-conducting composition, such as silicate cotton, slag wool, or asbestos. If the engine is situated more than 25 feet from the boiler, it will be advisable to fix a steam trap or separator in the pipe. Choose a simple form of trap; a good one is arranged with a Cam motion for quick opening, combined with a loose valve, which reduces the friction considerably and renders it less liable to stick. We have recently seen a new form of separator in use which appears to give capital results. It consists briefly of a circular cast-iron chamber with a branch connecting it to, and forming part of, the main steam pipe. The steam on entering the chamber is conducted to one side by a partition narrowed down at its orifice, so that in rushing in it acquires a whirling motion at a high velocity. The particles of water being of greater specific gravity than the vapour, are thrown outwards and run down the sides of the chamber, whilst the steam at the centre of the vortex, free from water, passes to the engine cylinder through a centre pipe provided for the purpose. This pipe is of trumpet form. The condensed water collects at the bottom of the chamber and is released by a drain-cock. Expansion steam-traps should be used with caution.

Stop and starting valves should in all cases be turned off or on gradually, in the first case not to stop the flow of steam suddenly and cause a recoil, and in the second to allow the pipes to warm and gradually expand. We have known many cases of fracture from steam being suddenly turned into cold pipes. All steam-pipes should have as few joints and elbows as possible; the pipe carrying the exhaust steam away should be of ample size; small exhaust-pipes cause back pressure on the piston, and consequent loss of power. The beats or pulsations made by the escape of the exhaust steam should be at regular intervals; if they are intermittent or irregular, steam is probably passing the piston or slide-valve which should be examined and adjusted. In connecting feed and steam pipes allowance should in all cases be made for expansion.

Covering Steam Boilers and Pipes.—There is undoubtedly a very considerable economy effected by covering steam boilers with a good non-conducting composition to prevent radiation of heat. In order to ascertain the degree of advantage obtainable by felting and lagging steam boilers, Mr. B. H. Thwaite, C.E., has recently carried out the following experiments upon a vertical boiler: A definite quantity of water was poured into a vessel sufficient to cover a square foot of plate surface; this vessel was externally lined with wood. The rise in the degree of heat during the hour's exposure was noted. The same height of water, with identical initial temperature, was then placed for the same time on the surface of the lagging, which consisted of three thicknesses of $\frac{3}{8}$-inch felt covered with $\frac{1}{2}$-inch tongued and grooved boards. On the naked plate it was found that 516·75 heat units per square foot were absorbed by the water, and on the lagged portion only 145·75 units per square foot were given off. This is equivalent to a reduction of wasteful radiation, due to the lagging, of 34 per cent., or with a vertical boiler, say 4 feet diameter and 9 feet high, working for ten hours, there would be a saving of some 70 lbs. of coal. These experiments should convince the most sceptical that any reasonable sum spent on covering a boiler is money very well laid out; and yet we find hundreds, or even thousands, of boilers in use without any covering at all, and the users complain of their coal bills. No wonder! Hatton gives the following as the steam saved by non-conducting coverings for steam-pipes relatively to the bare pipes, each composition being wrapped twice round with paper, with an outside cover of double-wrapped canvas, painted with two coats of paint, total thickness of each covering $1\frac{1}{2}$ inch: Hair felt, wood lagged, 96 per cent.; slag wool, wrapped in felt, 95; paper, hair felt, 93; air space, hair felt, 93; chopped straw, silicated, 92; bran, silicated, thin felt, 91; air space, bran, hair, 90; fossil meal and hair plaster, 89; air space and fine wool, 89; air space and fine cotton, 87; air space and goat's hair, 86; air space, paper pulp, hair, 84; clay, hair, flour, flax fibre, 84; larch turnings, hair, flour, 82; clay, sawdust, paper pulp, 80; flax fibre, clay, paper shavings, flour, 79; moss, hair, sawdust, flour, 79; thin hair felt, straw rope, 78; chalk, hair, flour, 78; charcoal, sawdust, hair, flour, 76; peat, sawdust, hair, flour, 74; pumice-stone, sawdust, clay, flour, 74; ashes, hair, cement, 72; asbestos paste, paper, 71; brick-dust, sand, flax, cement, 70; air space, tin-plate case, paper, 69; clay, flax refuse, 69; asbestos paper, brown paper, 68. Whatever covering is used it should be painted on the outside with a good fireproof paint.

Connecting a Series of Boilers.—In connecting a series of boilers together, unless they are all of the same age and condition, steam-reducing valves should be employed. These can be so arranged that any desired difference of pressure may be maintained, and steam let out of the high-pressure boiler when any fixed working pressure has been attained, and the valve automatically closed should the pressure fall below the desired point. Occasionally, in a battery of boilers one safety-valve is made to do duty for several boilers. This is a very dangerous plan, especially if stop-valves are provided for disconnecting the boilers. One of these may be closed for some reason, and should the attendant forget to open it a great pressure may be unconsciously generated, and a dangerous explosion may occur. Several disastrous explosions have really occurred from this very cause.

Each boiler in a series should have its separate safety-valve, pressure-gauge, and set of fittings; and on *no account should a stop-valve be placed between a boiler and a safety-valve*, or an explosion is almost certain to occur sooner or later. A water stop-valve should also be fitted to each boiler, so that the feed may be regulated by it, and by closing this and the steam stop-valve the boiler may be entirely disconnected from the others if required, or in case of steam-pipe bursting or other accident. The French Board of Trade insist that all boilers connected with others must be provided with self-acting check-valves to shut off the escape of steam, should the pipes connecting them fracture. Any valve of this kind should be gradual in its action.

Priming of Steam Boilers.—Priming or 'foaming,' or in other words, the production of 'wet' steam, may generally be said to arise from one of the following causes: (1) Want of steam space; (2) too much water in the boiler; (3) dirty feed-water; (4) bad circulation of water, or badly proportioned boiler; (5) grease in the boiler, and some kinds of boiler fluids, especially if put in in quantities, will cause priming; (6) too much steam drawn from the boiler causing a whirling motion on the water; (7) by forcing the fire. The amount of priming varies considerably with different boilers, and is to some extent under the control of the attendant. Perforated pipes or baffle plates will usually check priming to a certain extent, and a wooden grating, fastened by chains and allowed to float on the water immediately under where the steam is drawn from the boiler, will usually stop priming almost entirely.

Water Circulation in Boiler &c.—Unless a boiler is constructed so that when heat is applied to the water a rapid circulation of it can take place, it can never be worked with great economy. For instance, in tubular boilers, if the tubes are placed too close together, the heated globules of water are prevented rising as rapidly as they should do; hence the circulation becomes sluggish and detrimental to steam making. With a sluggish circulation the water cannot take up the heat of the fire quickly enough, and this is without doubt one of the causes of burnt plates. It is also important to economical working that ample space is allowed for the steam when made, as dry steam cannot be obtained from a confined space, and this is without doubt the chief cause of priming. As it is impossible for an attendant to get highly economical results from a badly designed boiler, it may not be entirely out of place in these pages to name a few points that are to be desired in the construction of a tolerably perfect one: (1) A boiler of a design that can be readily inspected, cleaned, or repaired. (2) A thorough circulation of the water through the boiler. (3) A large furnace or combustion chamber. (4) A sufficiency of water and steam space to avoid sudden fluctuations in the water level or steam pressure. (5) A large margin of strength over working pressure. (6) Stays, ends, strengthening rings, &c. arranged with an allowance for expansion. (7) Ample heating surface, with no joints or rivet heads exposed to the direct action of the fire. (8) Boiler to be properly fixed, and equipped with a full supply of fittings of the best type. (9) Chimney-stack to be correctly proportioned to the boiler and to the fuel to be burnt. (10) Boiler to be of a type suitable to the feed-water and fuel used, and to be made of first-class materials and with good workmanship.

It is of the utmost importance that all tubular boilers are kept free from incrustation, more especially at the tube ends nearest the fire, if not they will rapidly become burnt or cracked. This arises from the scale preventing the water taking up the heat fast enough ; consequently the tubes become overheated and unequally expanded, and therefore leak and crack. In a boiler where the circulation is bad this trouble is very much increased, and we have heard of a case of badly designed tubular boilers where the unequal expansion was so great that joints and rivets were loosened and leaks set up in all directions ; in fact, although new, these boilers were condemned as unsafe and removed. Before this was done, however, the joints were recaulked and rivets replaced, but they were soon as bad as ever. The boiler-makers sued for the cost of the boilers, but were defeated, the defence being mal-proportion, which was held to be proved. These boilers were afterwards rearranged—the same number of tubes differently placed being used—and worked well.

Plugging Leaky Tubes.—Split or leaky tubes may be plugged for temporary use with iron or wooden plugs. Care should be taken that the plugs are not too tight a fit, or the evil may be increased in driving. In using wooden plugs, unless the split is a short one and at the extreme end of the tube, it is a good plan to use two plugs, driving one in past the split and another to follow it. Iron plugs, with a collar on the one end to close the end of the tube, are also used. Small leaks at the tube ends may often be stopped by expanding the tube with an expander, but care must be taken that this operation is not carried too far, or the tube may be split. Many boiler-makers prefer to plug tubes with well-fitted ferrules. The author has used the following plan with success, and can recommend it. Make taper plugs of pine about 4 inches long, bore a hole through them, and drive them in flush with the end of the tube. Take a round rod or bar of wrought iron and screw a thread on each end ; pass the bar through the plugs and put on saucer-shaped washers filled with red lead, to cover each end of the tube, put on nuts and tighten up. If tubes are plugged under steam, damp down the fire with small coal and close the dampers.

Leaky feed-pipes &c. may usually be temporarily repaired by wrapping them tightly round with narrow bands of canvas coated with white lead. The bands should be, say, three inches wide, and overlap each other half way ; they should be very tightly tied on with waxed or tarred rope. Soft pine wood is the best to use for plugs, as the water penetrates the pores of the wood, causing it to swell, and the plug is thus held firmly in position. Oatmeal or any similar substance should not be introduced in a boiler to stop leaks, as they clog the water-gauge passages and valve-seats, which may result in serious accident ; at the same time they are liable to cause priming.

Drawing Tubes.—If the proper appliances are not to hand, drawing tubes is often a troublesome job, from accumulation of scale and other causes ; but as a competent engine-driver should be able to draw a tube, I give a note thereon. If the scale on the tubes is very hard, it may be cracked off by putting a red-hot bar into each tube before drawing. In the first place, cut off or bend in the ends of the tube, then pass a rod—arranged with an eye at one end and a nut and strong steel washer at the other—through the tube ; if you cannot draw by hand, fasten a pair of blocks on to the eye and pull the tube out. Be careful not to damage the tube-plate. Several handy appliances are now made for extracting ferrules.

Grinding in Cocks.—In case of leakage of the various cocks, a boiler-attendant should be capable of setting them right by regrinding, unless they are very much worn, when they should be renewed. If the plugs are worn irregularly, draw-file them first of all with a smooth file as true as may be, then take either flour of emery or powdered glass and mix with oil, and grind in the plug till it is a true fit, but not too tight or it will be more apt to stick when expanded by the heat. Do not use a file unless absolutely necessary, and grease the cocks well when replaced.

Repairing Boilers &c.—Part of the following notes are by a practical boiler-maker, and may be of service in the colonies and isolated districts where repairs have often to be executed by others than skilled boiler-makers: 'It is commonly noticed in boilers that have seams of rivets, exposed to the action of the fire, that after being at work for some time cracks begin to appear, running from the rivets to the centre of the plate. The cause is, one lap being covered by another prevents the water getting to the one nearest the fire; consequently the lap nearest the fire becomes hotter and expands to a much greater extent than any other part of the plate, and its constant unequal expansion and contraction, as the boiler alternately becomes hot and cold, inevitably results in a crack. These cracks may be temporarily repaired by drilling a hole in the extremity of them, so that the crack is completely drilled out, and by inserting a wrought-iron gas plug—and, as a rule, this may safely be done if the crack is not more than three inches long; but if of greater length do not tamper with it, but have the plate out if possible.'

'If it is not practicable to take the plate out, cut out so large a piece that the seams of the patch shall be as far from the fire as possible. Let it be well borne in mind that in addition to the two laps causing unequal expansion, the sediment or scale inside the boiler obstinately sticks in between the rivet head and under the edge of the lap, from whence it is seldom or never properly removed in cleaning the boiler. After drilling out the end of the crack, countersink the drilled hole, and also the hole in the seam above it, so that when rivets are again put in they will meet each other, or nearly so. Let the heads of these rivets be as thin as possible, so as not again to retain the heat or attract or harbour the dirt. Sometimes it will be observed that a crack in the seam is running from hole to hole between the rivets. This is always dangerous, and the cracked plate should be cut out and replaced by a new one as soon as possible. In putting patches on any part of a boiler, never cut a hole out with square corners like the inside of a picture; but cut the holes, which are to be covered with a patch, round, or as nearly circular as possible. But it is always better "not to put a patch on," but to cut out the defective plate and put in a new one, thus making the boiler as nearly as possible what it was when new.

'In putting a plate in a very old boiler, it is advisable to have it a little thinner than the old plates were when new, say $\frac{1}{16}$th of an inch. In putting on a new plate, arrange it, if possible, so that the caulking shall be done on the new iron; but never place the edge of the lap towards the fire, unless a considerable distance from it. After repairing the boiler, test it with cold water to double the working pressure; viz. if the boiler is worked to a pressure of 50 lbs. per square inch, test it to 100 lbs. &c. And in testing the boiler, notice if the top of the furnace tubes have any tendency to become flat. This is easily ascertained by placing two laths in the middle of the tube in the form of a cross—that is to say, one vertically and one horizontally. If the tube is giving way to the pressure, the vertical lath will bend, and the horizontal one will drop, as the tube assumes an oval shape, the horizontal diameter being the longest. If this occurs the tube should be strengthened, either with a ring or a Galloway tube ; if with a ring, keep a space between it and the tube, and pitch the rivets about 8 inches apart from centre to centre.'

If bolts are used in boiler repairs—which we do not recommend—they should be turned slightly concave, and the holes rhymered out to suit. Stays to ends, rings to interior tubes—in fact, staying of any kind—should not be made too rigid, but allowance given for expansion.

Leaks may in some cases be temporarily stopped by fitting a steel plate to the outline of the boiler and lining it with canvas covered with red lead, or with a stiff mixture of red and white lead and finely chopped hemp. The plate must be tightly wedged up.

In temporary repairs, where it is necessary to use ordinary bolts, a little hemp and red lead should be wrapped round the bolt under the head, and a washer covered with red lead should be placed under the nut. 'Soft' patches are, as a rule, objectionable, and should not be put on unless the boiler is old and ordinary rivetting and caulking may strain it. Caulk the edges of the patch instead of the old plate. Blisters should be cut off or rivetted down, but if very extensive they may have to be cut out. If a crown sheet requires several small patches, it would be better to cut it out altogether. If crown sheets are slightly bulged, they may in many cases be straightened by heating them to a dull red by means of a charcoal fire and forcing them up to their original position with a screw-jack. If this is attempted the adjoining plates should be wedged, and the bulged plate may require bracing.

When strengthening rings are fitted, distance ferrules should be used, and not thick iron washers. Care should be taken that all rivets fill the holes properly, that the holes are fair with one another, and that the rivets are sufficiently long to make a proper head. Brackets are best fastened with rivets. All seams should be carefully caulked, and any welding that may be necessary should be very carefully done, as imperfect welds have been the cause of many accidents. For repairs, employ a skilled boiler-maker wherever possible.

Buying Second-hand Boilers.—Our advice as regards buying second-hand boilers is don't, unless you know the exact age of it, and the maker as one of repute. After, say, fifteen years' working—according to the quality of the steel and the treatment it has received—the nature of the steel has, to a large extent, become changed from a fibrous to a granular iron, and the boiler is then dear at any price. Before purchasing a second-hand boiler, it is most undoubtedly advisable to get a practical boiler-maker to inspect and test it; as being presumably up to the tricks of the trade, he should be able to detect any thin places, joints rusted up with sal-ammoniac, and cast-iron borings, and other little arrangements not unknown amongst dealers in boilers.

Firing Steam Boilers.—The economical working and longevity of a steam boiler depends, in the first place, largely on the following points: (1) The type of boiler employed; (2) how it is fixed; (3) the fuel and feed-water used. In selecting a boiler the chief points to bear in mind are what kind of water and fuel it will be necessary to use. The feed-water should in all cases be tested, and, if found impure, of course a simple form of boiler easily cleaned should be selected. In any case, for economical firing—whatever type of boiler is selected—the author recommends the employment of a fire-box or combustion chamber of ample dimensions. There is little doubt that hundreds of boilers are in use in which the combustion chambers are far too cramped ; consequently, to keep up a fair head of steam, excessive firing has to be resorted to, the result being the reverse of economical both as regards the consumption of fuel and the longevity of the boiler.

Having selected the best type of boiler for the special purpose to which it has to be put, the very important question presents itself, which is the best way of firing it—or, in other words, the best way to consume the fuel employed—so as to ensure perfect combustion, at the same time securing the largest possible amount of duty from each ton of fuel employed? The effective combustion of fuel may be said to depend chiefly on the following points :—

1. Construction of the combustion chamber or fire-box. 2. The admission of the right quantity of air to the furnace. 3. The proper regulation of the draught. 4. Regular and even firing. (1) Many Cornish and Lancashire boilers have been built in which the combustion chamber has been made much too shallow and of too small cubic capacity, with intention probably of bringing the fire as near the boiler as possible, and thus extracting more heat from it. This idea must be held to be altogether wrong, as in the confined space the draught is much increased, and the heat, therefore, is carried rapidly away. The small size of the furnace also will not allow of the perfect combustion of the various gases, and, lastly, the fire itself comes in direct contact with the boiler plates, which should be avoided. (2) The admission of the right quantity of air to the furnace is a matter of great importance, but one often neglected. In the first place, care must be taken that sufficient air space between the fire-bars is allowed. It is impossible, however, to lay down an absolute rule as to what is the proper amount of air space to secure the most perfect combustion, as much depends on the nature of the fuel and the velocity of the

draught through the flues, but, roughly speaking, an area of from five to six square inches for each square foot of grate surface should be provided. The air admitted through the fire-bars is not, as a rule, sufficient to promote efficient combustion, and air is usually admitted through the door or bridge of the furnace. The author is of opinion that hot air admitted from the bridge is efficacious in promoting combustion and preventing smoke, and several very excellent plans for supplying and regulating the hot air are in use. Forcing a boiler has a tendency to produce smoke ; the great factor in perfect combustion I take to be plenty of grate area and combustion space. It must be borne in mind that when fuel in a furnace is in a state of combustion, it burns of the carbon it contains only an amount proportionate to the amount of oxygen that is brought in contact with it. In order to enable that combustion to take place the oxygen must be raised to a high temperature before it will combine with the fluid carbon. If it does not combine with the fluid carbon, it drives the latter before it until it reaches the outside air, and disperses in the form of carbonic oxide or carbonic acid gas, as the case may be. Where the atmospheric air (or oxygen) is admitted through the door and front bars of the grate, the velocity of the draught is usually such as to drive the atmospheric air straight over the bed of the furnace, and, before it has reached a degree of heat high enough to enable it to combine with the fluid carbon evolved from the coal, it is driven over the fire, and consequently, instead of combining with the fluid carbon, it drives it to the upper air unconsumed. Various systems of mechanical stoking have been introduced during late years, in some cases with considerable success ; but exigencies of space prevent more than a passing notice here. Whatever kind of stoking is pursued, it may be taken as an axiom that, the shallower the combustion chamber is, the lighter should be the fire in proportion (see page 9).

APPROXIMATE TEMPERATURE INDICATED BY COLOUR OF FIRE.

	Degs. Fahr.
Faint red	960
Bright red	1,300
Cherry red	1,600
Dull orange	2,000
Bright orange	2,100
White heat	2,400
Brilliant white heat	2,700

To convert Fahrenheit into Centigrade.—Subtract 32, and divide by 1·8.

To convert Centigrade into Fahrenheit.—Multiply by 1·8 and add 32.

Evaporative Power of Fuels. — The average evaporative power of fuels may be stated as follows, presupposing each to be good of their kind :—

1 lb. steam coal	will evaporate	9 lbs. water	raised to	212° Fahr.
2 lbs. of dry peat	,,	,,	,,	,,
$2\frac{1}{2}$ lbs. of dry wood	,,	,,	,,	,,
$3\frac{1}{4}$ lbs. of cotton stalks	,,	,,	,,	,,
$3\frac{1}{2}$ lbs. of brushwood	,,	,,	,,	,,
$3\frac{3}{4}$ lbs. of straw	,,	,,	,,	,,
4 lbs. sugar-cane refuse	,,	,,	,,	,,

In the best class of engines, and with the best steam coal, the average consumption per indicated horse-power per hour should be as follows :—

Compound condensing engine . . .	from $1\frac{1}{2}$ lbs.	to	2	lbs.
Locomotive engines	,, 2	,,	$2\frac{1}{2}$	,,
High-pressure non-condensing engine . .	,, 3	,,	4	,,

Owing to the evaporative efficiency of many boilers being defective, to incrustation, bad stoking, &c., these figures are, however, generally considerably exceeded.

Exposing Coal to the Weather.—The author recommends that in all cases coals should be kept under cover, as there is little doubt that coals exposed to the weather lose considerably in value.

Dr. Varrentrass has ascertained a loss of more than one-third in the weight of a sample of coal exposed for some time to the air, and he states that the quality of the coal had undergone a still greater deterioration. The loss is due to a slow combustion of the volatile gases of the coal, which gradually diminish in amount, whilst the proportions of carbon, ash, and sulphur are increased. In some experiments made, the gas furnished diminished 45 per cent. and the heating power 47 per cent. in a coal which had been exposed, and the same coal under shelter lost only 25 per cent. as a gas generator and 10 per cent. as a heat producer. Anthracite, as might be expected, suffers least from exposure to the atmosphere, and the bituminous coals are those which lose most. As we have before remarked, the economical working of steam depends as much on the care of the stoker as on the fuel used, and in some establishments, and on many railways, a premium is offered to stokers on the amount of coal saved, with very satisfactory results. (A careless or bad stoker is dear at any price.) Steam-users should in all cases check the consumption of coal as the engine and boilers get older, with what it was when new, as defects in working may often be detected in this way.

Boiler Chimneys.—The efficient and economical working of a steam boiler depends to a considerable extent on the correct proportion of the chimney, which should be designed so that a steady and even flow of air is maintained. There is considerable diversity of opinion as to correct size and proportion of boiler chimneys. Wilson gives as a common rule, derived from experience, that the flues and area of the chimney top should be made from one-eighth to one-tenth the area of the fire-grate, without taking into account the height of the chimney. Another useful rule is to allow from 2 to 3 feet (square) for each boiler having about 30 square feet of fire-grate, the former allowance answering for chimneys over 150 feet high with not over six furnaces. There are many tall chimneys over 200 feet answering well with only from $1\frac{1}{4}$ foot to $1\frac{3}{4}$ foot square of top opening for every 30 square feet of fire-grate. Where more than half-a-dozen boilers are working together with one chimney in common, the flues should be made larger than the area of the chimney, as they become contracted when soot gathers. If the area of a chimney is excessively large, the draught may be damaged by downward currents. The author of 'Modern Steam Practice' says: To determine the area of the top of the chimney for a given consumption of coal per hour, for Cornish boilers (the average consumption for Cornish boilers being 10 lbs. per nominal horse-power), multiply the number of pounds consumed per hour by 12, and divide the product by the square root of the height of the chimney in feet (the usual height for factory chimneys being 80 feet), and the quotient is the area at the top of the chimney. Thus, for 40 nominal horse-power—

$$\frac{40 \times 10 \times 12}{\sqrt{80}} = 539, \text{ say 26 in. diameter,}$$

or 23 square inches at the top. It is always preferable to make an allowance over and above this for the convenience of leading other flues into it. The flues and base of chimney should be lined with firebrick. A round chimney gives a better draught than a square one, and a straight flue than a tapering one. If it be compulsory to use a chimney of too contracted dimensions, an artificial draught may be created by a jet of steam, but this is not recommended for constant use, as it is decidedly wasteful. Of course, the nature of the fuel to be used is an important factor in designing boiler chimneys, but the fact remains, that whatever fuel is used its combustion is influenced to a considerable extent by the height and cross-section area of the chimney, therefore I think the question of chimney design should receive more careful attention than is at present accorded to it. We append a table of proportions on the American system and as calculated by Mr. Armstrong; we prefer the latter.

Table showing the Proper Diameter and Height of Chimney for any Kind of Fuel.

Nominal h.p. of boiler	Height of chimney in feet	Inside diameter at top	
		American	Armstrong
		ft. in.	ft. in.
10	60	1 2	1 6
12	75	1 2	1 8
16	90	1 4	1 10
20	99	1 5	2 0
30	105	1 9	2 6
50	120	2 2	3 0
70	120	2 6	3 6
90	120	2 10	4 0
120	135	3 2	4 6
160	150	3 7	5 0
200	165	3 11	5 6
250	180	4 4	6 0

Mr. Armstrong says the proportions he gives have been found to answer well with inferior steam coal.

To find the Horse-power of Boilers.—To find the so-called nominal horse-power of boilers the following rules may be used :—*Cornish boilers* : Add the diameter of the boiler and the diameter of the flue together in feet, multiply the sum by the length in feet, and divide the product by 8. *Lancashire boilers* : Add the diameters of both flues and the diameter of the boiler together in feet, multiply the sum by the length in feet, and divide the product by 8. *Vertical cross-tube boilers* (Hutton) : Add together the diameter of the shell, the diameter of the fire-box, the diameters of all the tubes and the diameter of the uptake tube, all in feet ; multiply the sum by the length in feet, and divide by 10. *Vertical tubular boilers* : Add together the diameter of the shell, the diameter of the fire-box, and the diameters of all the tubes, all in feet ; multiply the sum by the length in feet and divide by 12. The actual horse-power of a boiler can be obtained by calculating the number of cubic feet of water evaporated per hour.

To find the Number of Cubic Feet of Water Evaporated per Hour.—Multiply the number of square feet of water surface by the evaporation in inches of gauge-glass, multiply the product by 5, and divide the result by the number of minutes occupied in evaporation.

To find the Quantity of Water in lbs. Evaporated per lb. of Coal.—Multiply the number of cubic feet of water evaporated per hour by 62·5, and divide the product by the quantity of coals consumed per hour.

A Useful Table for Boiler Attendants and Engineers.—Some simple and convenient method of calculating the volume of the steam or water space in steam boilers is many times of great assistance to engineers and others who are connected with their management; the following table will be found convenient for this purpose, and with the accompanying explanations should be useful:—

TABLE OF THE AREAS OF CIRCULAR SEGMENTS FOR DIAMETER = 1.

The heights are in parts of the diameter of the circle.

Height	Area	Height	Area	Height	Area
·001	·000042	·036	·009008	·071	·024680
·002	·000119	·037	·009383	·072	·025196
·003	·000219	·038	·009764	·073	·025714
·004	·000337	·039	·010148	·074	·026236
·005	·000471	·040	·010538	·075	·026761
·006	·000619	·041	·010932	·076	·027290
·007	·000779	·042	·011331	·077	·027821
·008	·000952	·043	·011734	·078	·028356
·009	·001135	·044	·012142	·079	·028894
·010	·001329	·045	·012555	·080	·029435
·011	·001533	·046	·012971	·081	·029979
·012	·001746	·047	·013393	·082	·030526
·013	·001969	·048	·013818	·083	·031077
·014	·002199	·049	·014248	·084	·031630
·015	·002438	·050	·014681	·085	·032186
·016	·002685	·051	·015119	·086	·032746
·017	·002940	·052	·015561	·087	·033308
·018	·003202	·053	·016008	·088	·033873
·019	·003472	·054	·016458	·089	·034441
·020	·003749	·055	·016912	·090	·035012
·021	·004032	·056	·017369	·091	·035586
·022	·004322	·057	·017831	·092	·036162
·023	·004619	·058	·018297	·093	·036742
·024	·004922	·059	·018766	·094	·037324
·025	·005231	·060	·019239	·095	·037909
·026	·005546	·061	·019716	·096	·038497
·027	·005867	·062	·020197	·097	·039087
·028	·006194	·063	·020681	·098	·039681
·029	·006527	·064	·021168	·199	·040277
·030	·006866	·065	·021660	·100	·040875
·031	·007209	·066	·022155	·101	·041477
·032	·007559	·067	·022653	·102	·042081
·033	·007913	·068	·023155	·103	·042687
·034	·008273	·069	·023660	·104	·043296
·035	·008638	·070	·024168	·105	·043908

TABLE OF AREAS—*continued.*

Height	Area	Height	Area	Height	Area
·106	·044523	·150	·073875	·194	·107051
·107	·045140	·151	·074590	·195	·107843
·108	·045759	·152	·075307	·196	·108636
·109	·046381	·153	·076026	·197	·109431
·110	·047006	·154	·076747	·198	·110227
·111	·047633	·155	·077470	·199	·111025
·112	·048262	·156	·078194	·200	·111824
·113	·048894	·157	·078921	·201	·112625
·114	·049529	·158	·079650	·202	·113427
·115	·050165	·159	·080380	·203	·114321
·116	·050805	·160	·081112	·204	·115036
·117	·051446	·161	·081847	·205	·115842
·118	·052090	·162	·082582	·206	·116651
·119	·052737	·163	·083320	·207	·117460
·120	·053385	·164	·084060	·208	·118271
·121	·054037	·165	·084801	·209	·119084
·122	·054690	·166	·085545	·210	·119898
·123	·055346	·167	·086290	·211	·120713
·124	·056004	·168	·087037	·212	·121530
·125	·056664	·169	·087785	·213	·122348
·126	·057327	·170	·088536	·214	·123167
·127	·057991	·171	·089288	·215	·123988
·128	·058658	·172	·090042	·216	·124811
·129	·059328	·173	·090797	·217	·125634
·130	·059999	·174	·091555	·218	·126459
·131	·060673	·175	·092314	·219	·127286
·132	·061349	·176	·093074	·220	·128114
·133	·062027	·177	·093837	·221	·128943
·134	·062707	·178	·094601	·222	·129773
·135	·063389	·179	·095367	·223	·130605
·136	·064074	·180	·096135	·224	·131438
·137	·064761	·181	·096904	·225	·132273
·138	·065449	·182	·097675	·226	·133109
·139	·066140	·183	·098447	·227	·133946
·140	·066833	·184	·099221	·228	·134784
·141	·067528	·185	·099997	·229	·135624
·142	·068225	·186	·102774	·230	·136465
·143	·068924	·187	·101553	·231	·137307
·144	·069620	·188	·102334	·232	·138151
·145	·070329	·189	·103116	·233	·138996
·146	·071034	·190	·103900	·234	·139842
·147	·071741	·191	·104686	·235	·140689
·148	·072450	·192	·105472	·236	·141538
·149	·073162	·193	·106261	·237	·142388

TABLE OF AREAS—*continued.*

Height	Area	Height	Area	Height	Area
·238	·143239	·282	·181818	·326	·222278
·239	·144091	·283	·182718	·327	·223216
·240	·144945	·284	·183619	·328	·224154
·241	·145800	·285	·184522	·329	·225094
·242	·146656	·286	·185425	·330	·226034
·243	·147513	·287	·186329	·331	·226974
·244	·148371	·288	·187235	·332	·227916
·245	·149231	·289	·188141	·333	·228858
·246	·150091	·290	·189048	·334	·229801
·247	·150953	·291	·189956	·335	·230745
·248	·151816	·292	·190865	·336	·231689
·249	·152681	·293	·191774	·337	·232634
·250	·153546	·294	·192685	·338	·233580
·251	·154413	·295	·193597	·339	·234526
·252	·155281	·296	·194509	·340	·235473
·253	·156149	·297	·195423	·341	·236421
·254	·157019	·298	·196337	·342	·237369
·255	·157891	·299	·197252	·343	·238319
·256	·158763	·300	·198168	·344	·239268
·257	·159636	·301	·199085	·345	·240219
·258	·1605[illegible]1	·302	·200003	·346	·241170
·259	·161386	·303	·200922	·347	·242122
·260	·162263	·304	·201841	·348	·243074
·261	·163141	·305	·202762	·349	·244027
·262	·164020	·306	·203683	·350	·244980
·263	·164900	·307	·204605	·351	·245935
·264	·165781	·308	·205528	·352	·246890
·265	·166663	·309	·206452	·353	·247845
·266	·167546	·310	·207376	·354	·248801
·267	·168431	·311	·208302	·355	·249758
·268	·169316	·312	·209228	·356	·250715
·269	·170202	·313	·210155	·357	·251673
·270	·171090	·314	·211083	·358	·252632
·271	·171978	·315	·212011	·359	·253591
·272	·172868	·316	·212941	·360	·254551
·273	·173758	·317	·213871	·361	·255511
·274	·174650	·318	·214802	·362	·256472
·275	·175542	·319	·215734	·363	·257433
·276	·176436	·320	·216666	·364	·258395
·277	·177330	·321	·217600	·365	·259358
·278	·178226	·322	·218534	·366	·260321
·279	·179112	·323	·219469	·367	·261285
·280	·180020	·324	·220404	·368	·262249
·281	·180918	·325	·221341	·369	·263214

TABLE OF AREAS—*continued.*

Height	Area	Height	Area	Height	Area
·370	·264179	·414	·307125	·458	·350749
·371	·265145	·415	·308110	·459	·351745
·372	·266111	·416	·309096	·460	·352742
·373	·267078	·417	·310082	·461	·353739
·374	·268046	·418	·311068	·462	·354736
·375	·269014	·419	·312055	·463	·355733
·376	·269982	·420	·313042	·464	·356730
·377	·270951	·421	·314029	·465	·357728
·378	·271921	·422	·315017	·466	·358725
·379	·272891	·423	·316005	·467	·359723
·380	·273861	·424	·316993	·468	·360721
·381	·274832	·425	·317981	·469	·361719
·382	·275804	·426	·318970	·470	·362717
·383	·276776	·427	·319959	·471	·363715
·384	·277748	·428	·320949	·472	·364714
·385	·278721	·429	·321938	·473	·365712
·386	·279695	·430	·322928	·474	·366711
·387	·280669	·431	·323919	·475	·367710
·388	·281643	·432	·324909	·476	·368708
·389	·282618	·433	·325900	·477	·369707
·390	·283593	·434	·326891	·478	·370706
·391	·284569	·435	·327883	·479	·371705
·392	·285545	·436	·328874	·480	·372704
·393	·286521	·437	·329866	·481	·373704
·394	·287499	·438	·330858	·482	·374703
·395	·288476	·439	·331851	·483	·375702
·396	·289454	·440	·332843	·484	·376702
·397	·290432	·441	·333836	·485	·377701
·398	·291411	·442	·334829	·486	·378701
·399	·292390	·443	·335823	·487	·379701
·400	·293370	·444	·336816	·488	·380700
·401	·294350	·445	·337810	·489	·381700
·402	·295330	·446	·338804	·490	·382700
·403	·296311	·447	·339799	·491	·383700
·404	·297292	·448	·340793	·492	·384699
·405	·298274	·449	·341788	·493	·385699
·406	·299256	·450	·342783	·494	·386699
·407	·300238	·451	·343778	·495	·387699
·408	·301221	·452	·344773	·496	·388699
·409	·302204	·453	·345768	·497	·389699
·410	·303187	·454	·346764	·498	·390699
·411	·304171	·455	·347760	·499	·391699
·412	·305156	·456	·348756	·500	·392699
·413	·306140	·457	·349752		

The table gives the area of circular segments of various heights for a circle whose diameter is unity. The first column, marked 'height,' is the height of the segments in parts of the diameter of the boiler. Thus the first number ·001 refers to a segment whose height is $\frac{1}{1000}$ of the diameter of the boiler; the second, to one whose height is $\frac{2}{1000}$ of the diameter of the boiler, and similarly for each one-thousandth part of the diameter up to a complete semicircle. $\frac{1}{1000}$ of the diameter of a 6-foot boiler would be the $\frac{1}{14}$ of an inch.

As the area of circles, or similar parts of circles of different sizes, are directly proportional to the squares of their diameters, it follows that if we wish to find the volume of steam space of any given boiler—for instance, one whose diameter is 6 feet, with water line 2 feet from the top—it will only be necessary to find what part of the diameter, 6 feet, the 2-foot height of steam space is, find the quotient in the column of heights in the table, take out the corresponding area and multiply it by the square of the diameter, which in this case would be $6 \times 6 = 36$.

Thus: $2 \div 6 = {\cdot}333$. In the table the area of a segment whose height is ·333 is seen to be ·228858. This multiplied by $36 = 8{\cdot}238888$ square feet for the area of the cross section of the steam space. This area multiplied by the length of the boiler will give the volume of the steam space in the cubic feet. In the case of a 16-foot boiler this would be $8{\cdot}238888 \times 15 = 123{\cdot}58$ cubic feet.

The table is extracted from Trautwine's 'Engineers' Pocket-book,' and as it gives results for such small increments of height, it will be found of great value where accuracy is desired.

The volume of water space is easily found by subtracting the area of steam space from area of whole boiler, deducting area of tubes, and multiplying by the length of boiler, as in former case.

The table will also be found useful when designing boilers in calculating the area of portions of the head above the tubes which require bracing, or for any purpose where it is required to know the area of a segment of a circle.

CHAPTER III.

MANAGEMENT OF STEAM ENGINES AND BOILERS.

Engines.

Pounding or Knocking of Engines.—Pounding or knocking may arise from a variety of causes. If the knocking is at the end of the stroke when the crank is on the 'dead centre,' it may arise from wear on the connecting-rod bearings, or from their not being keyed up tight enough, or from the piston-rings being broken, too loose at the guide-bar end, or from a ridge or inequalities in the cylinder or guide-bars. Knocking, when the crank is at half-stroke, will not be caused by any of the above reasons except the piston or piston-rings being loose, which would cause a knocking sound as the crank came over the dead-centre and at the end of each stroke. Knocking or clicking of piston-rings may also be caused through water being in the cylinder, either from the boiler priming or from condensation oı steam. It may also arise from the engine-shaft, crosshead, or slides being out of line, or from insufficient cushioning oı the piston, or from a slack nut at the end of the slide-valve rod, or valve rod bent from an accumulation of dirt. Knocking may also be caused from the axes of all the journals not being parallel.

Engine Cylinders Cracking.—There is little doubt that the 'mysterious' cracking of engine cylinders which occasionally occurs arises in many cases from the want of ordinary precautions on the part of the driver. Drivers often get up steam and start their engines as soon as possible, and the steam is let into the cylinder when it is cold, consequently an immense strain from sudden and unequal expansion is set up. It is therefore advisable, especially with large engines—more particularly in frosty weather or exposed situations—that the cylinder be thoroughly warmed before starting. There are, of course, other reasons for cylinders cracking, such as the use of improper or unsound metal in their construction, improper proportion of metal, water or ice in the cylinder, broken piston, engine running away, &c. The cylinder, if steam-jacketed or not, should in all cases be carefully covered with a good non-conducting material to prevent radiation of heat.

Quick Methods of Setting a Slide-valve.—1. Make the eccentric-rod of such a length as will permit the valve to open equally at both ends of the stroke. Then put the crank on the dead-centre, and turn the eccentric round the same way as the engine is intended to go, altering until the valve moves through a distance sufficient to give the required lead, and you may rely on its being the same on the opposite side. 2. Another plan (Dunn). Remove lid from steam-chest, revolve the main shaft or slack the set screws in eccentric, and revolve eccentric until full throw of same is made in one direction, opening the port to its largest size. Now make a tapered wedge out of a lath and slip it down in open port, marking with a knife or pencil the edge of wedge on valve-seat. Now revolve eccentric until full throw is made towards opposite end of steam-chest, and until port is open to its largest size; then slip the wedge down in port as before, marking on valve-seat as before; then with a rule divide the distance between the two lines, on edge of wedge, marking a third line in the centre; then, with the eccentric at full throw, lengthen or shorten the Cam rod until the wedge, with its centre line, fits one port neatly, and it will fit the other one as neatly when full throw is made in the opposite direction. Now place your engine on a centre and revolve eccentric until the port over the end of cylinder, in which the follower is placed, has opened about one-sixteenth of an inch, and tighten your set screws. This done, your slide-valve, also your eccentric, is properly adjusted, and no time wasted in hunting dead-centre or chalk marking fly-wheels.

Piston-rings.—In fitting in cast-iron piston-rings of the ordinary construction, the author has for some time done away with springs, wedges, or other devices for expanding the rings and simply relies on the spring in the ring itself, and the result has been in every way satisfactory. When rings are expanded in the ordinary way, they are simply made oval, and at the same time the friction of working, and consequent wear on the rings and cylinder, is considerably increased. Space will not permit of noticing here any of the numerous forms of piston-rings that have been introduced. Some of these are very good, but in many of them the expanding force is more than is required to keep a tight piston, consequently a considerable loss from unnecessary friction often takes place. What is required is a perfectly true cylinder and piston, with slight expansive force only on the rings. If the cylinder is in good condition, very little expansion on the rings is necessary; but if it is scored or grooved, no amount of setting out will make a tight joint, and the friction of working is largely increased. In the case of grooving, the cylinder should be rebored; the steam thus saved will very soon pay for the cost of this. We have found thin rings, as a rule, to be preferable to thicker ones.

Set screws acting on springs are objectionable; but should they be fitted, the driver should be very careful as to their setting up. The author has seen many rings and cylinders greatly misused through the medium of set screws. Piston-rings in which the expanding force consists of springs, may be acted on disadvantageously by the steam getting between the springs, or by their getting clogged up with grease or dirt. A good cast-iron ring is very durable, will wear better, work with less friction, and is generally to be preferred to many of the spring rings in use. The skilful attendant will take great pride in the condition of the cylinder, and with careful lubrication and management will keep the face of the cylinder as smooth as glass.

Piston-rod Packings.—A vast number of packings, all warranted to be the 'best,' are now manufactured. The author does not pretend to select a packing as the best for all duties; for high speeds and rough usage he has found the various preparations of asbestos extremely useful, as it has the property of resisting heat to a very high degree. It is manufactured in the form of cloth and also made up into ropes or blocks, with rubber cord or rubber inlaid. For very high speeds and intense friction, the author can recommend it made in the form of yarn and combined with soapstone, as this prevents the packing getting hard and losing its elasticity. Asbestos, if of good quality and properly prepared and used, has the additional advantage of requiring comparatively little lubrication, and is not affected by acids or moisture. Cotton rope packing, with an interior core of French chalk, is liked by many drivers; it is easily applied and can be recommended for moderate duties. Several forms of metallic packing are extremely serviceable, and will last a long time if carefully made and fitted, and the rods kept in first-class order and perfectly true.

It is important with whatever packing is used that the box is not filled too full and that the gland is screwed up equally and evenly all round, or the packing will be compressed unevenly and may cause leakage, or the gland may pinch and cause undue friction on the piston-rod. When a gland is properly packed and screwed up it should be sufficiently slack that the packing has room to expand slightly. If the gland is screwed up too tight the packing soon becomes hard and leaky. In packing with rope packing cut it into lengths slightly less than the circumference of the rod, and break joint with every piece that is put in. If ordinary hemp or spun yarn packing is used, it should be cut into lengths of, say, two feet or longer, according to the size of the rod, well soaked in grease and passed round the rod, each turn being evenly pushed into the stuffing-box with a wooden rod until it is nearly full. The author has had considerable experience with metallic packing, and if it is carefully made and arranged to automatically adjust itself to the motion and gear of the rod, there is really nothing superior to it, especially for high speeds and energetic friction. Many failures of metallic packing have arisen from the packing being non-adjustable or fitted to worn or untrue rods or by being screwed up too tight.

Whatever elastic packing is used, it is important that a suitable lubricant is employed. Many oils containing free or fatty acids, which are rapidly developed under the action of steam, are used for this purpose, consequently the decomposed oil and carbonaceous residue often glazes and hardens the packing, rendering it ineffective in use and requiring constant renewal. This is particularly the case when superheated steam is used.

If the gland leaks, do not put a piece of new packing on the top of the old, but take an early opportunity of removing the whole of it. If packing is allowed to get old and hard it will very rapidly score and cut the rod, rendering it difficult to get a perfectly steam-tight joint.

Governor Gear.—To insure steady running it is important that the governor gear is kept in first-class order and carefully lubricated. If it is allowed to run dry, or an oil is used that is given to gum up, it will run unevenly. If the governor is driven by a belt, unsteady running may be caused by the slipping or from its not running true, and perhaps bearing hard against a pulley flange. The belt should be of ample width, be evenly jointed, and kept pliable. We have seen many governors so placed that they had to be driven by a very short belt, which had therefore to be kept unduly tight. When the joints or gear show signs of wear have them seen to, as to be effective the whole governor should be in a thoroughly sensitive condition.

Sight-feed Lubricators.—Sight-feed lubricators for engine cylinders have of late come considerably into use, and are without doubt a distinct improvement over ordinary grease cups, as with these latter the piston may be running perfectly dry and the cylinder may be scored and the rings cut out before the attendant is aware of it. A good sight-feed lubricator only requires filling and regulating, say, once a day or less often than this, and the amount of oil passed into the cylinder can be adjusted to the greatest nicety. The old-fashioned tallow cup is in comparison very wasteful, as when filled up it floods the cylinder with oil or grease for a short time, and this being rapidly cleared away by the strokes of the piston, the cylinder is comparatively dry in a little time. A very considerable economy in oil is effected by the use of sight-feed lubricators, as they can be adjusted to supply the minimum amount of oil required to keep the cylinder properly lubricated.

Hot Bearings.—Heated bearings may arise from a variety of causes, such as, (1) Bearings of insufficient area for the pressure or strain put on them ; (2) engine running at short centres with a tight belt ; (3) bad-fitting or seamy shaft ; (4) bearings screwed up too tight ; (5) insufficient lubrication, improper or bad oil ; (6) dust or dirt in the bearings, oil grooves too shallow or oilways stopped ; (7) bearings will also stretch and pinch the shaft from being allowed to run slack or get out of line or level ; (8) from oil-boxes or lubricators being or becoming airtight and preventing the proper flow of the oil ; (9) from the axes of all the journals not being parallel, or from the shaft not bedding evenly on the bottom of the bearings.

Hot Crank-pin Bearings.—More particularly with engines in which the connecting-rod is arranged to work on to a crank-pin, considerable trouble is often experienced through the bearings heating. This may arise from their being poorly fitted, from requiring adjustment, from want of proper lubrication, or from the bearings being made too thin, sufficient metal not being provided to carry off the heat engendered from working when the bearing was slightly out of order. Apparently well-fitted bearings may heat from another cause and one that has puzzled a good many in detecting, and that is from the connecting-rod being out of line. To detect this take the connecting-rod out of the cross-head and key it up tightly on the crank-pin. Now move the rod up and down and see that it drops truly into the bearing on the cross-head ; if it does not, you will know it is out of line and should be overhauled and adjusted at once, as the bearing will never run cool under these conditions, it being very much strained and the area in contact with the crank-pin being largely reduced. If on examination you find the bearings are wearing bell-mouthed you may conclude it arises from the last-mentioned cause.

A similar trouble may arise with engines in which a sweep crank is used, but it is usually not so pronounced.

Engine Varnished.—If the engine is given a couple of coats of varnish over the ordinary paint, it can be kept much cleaner, and with less labour, than if left in the usual way, as all grease and dirt can be readily wiped off; at the same time the painted surface is protected.

In Case of Engine Breaking Down.—Should the engine break down from any cause, and there is a good pressure of steam or steam is rising, (1) turn on the feed, (2) try the safety-valve, (3) close the dampers, and (4) open the furnace-door.

Cracking of Crank-shaft.—Should a fine crack be discovered in the crank-shaft it may be stopped extending, at any rate for a time, by drilling a small hole into the shaft at the end of the crack. In putting in a new shaft see that it is rounded or filleted in the corners of the bearings; shafts left square, as is often done, are much more likely to crack than if rounded. In starting a new shaft or engine let it run without load for a time, and carefully adjust and humour the bearings until they are dead true; a little care in this way often saves endless trouble and annoyance afterwards.

Set of Tools and Duplicates.—A complete set of tools, spanners for all nuts, speed-recorder, duplicate piston-rings, gauge-glasses, packing, fusible plugs, &c., should be kept in the engine-room ready for any emergency.

Buying Second-hand Engines.—Some of the remarks with regard to buying second-hand boilers apply equally well to engines.

In examining an engine see that the cylinder is not worn hollow or scored, or it may require reboring ; see that the slide-valve, governor, gear, pump and bearings are in good condition. If the engine is of poor design or make or out of date, do not buy at any price, as the waste of steam would very soon amount to enough to buy an engine of the most advanced construction.

Making Red-lead Joints for Cylinder Covers &c. In making a new joint be sure that all the old lead is removed from both faces of the old one. Then wipe the faces over with waste dipped in boiled linseed oil. Work the lead up till it is soft and pliable, and remove all grit and lumps. It should then be rolled in the hands into thin ropes about $\frac{3}{8}$ in. in diameter, and laid on once round inside the bolt-holes. The two faces must now be brought together carefully and tightened equally all round. Tar-twine, hemp, string, wire-gauze, &c., should be avoided, as they prevent the faces of the joint coming close together. When joints are accurately faced very little red lead is required. For rough joints, tar-twine &c. may be used. Red-lead joints are often made much too thick, consequently the steam more readily leaks. Joints made of red lead should, if possible, be left some hours to set before being tried. When joints have been accurately faced a thin mixture of red and white lead and boiled oil makes an extremely tight joint, or a good joint may be made with two thicknesses of brown paper painted with boiled oil. When joints are made between male and female threads, such as screwed pipes and sockets, bolts, or studs screwed into boiler plates &c., liquid red lead is used, and should be put on the female

F

thread for inside pressure and on the male for outside pressure. The steam thus in each case forces any surplus lead into the thread and forms a more reliable joint, whereas when it is applied in the reverse way the threads are left bare, leaving nothing to strengthen the joint. Gaskets for manhole joints should be carefully made of elastic and tough material, and the joint made only sufficiently thick to overcome any inequalities in the plates; thick joints are a mistake. Should there be any inequality on the faces of the manhole plate and ring, care should be taken that the plate is not screwed up with excessive force, or the ring may be cracked, and, remaining undiscovered, lead to an accident. Both manhole and ring should have a perfectly flat face to make a good joint. For some joints graphite is now used instead of red lead.

High-pressure Steam Joints.—For making difficult joints for high pressure, or where there is a considerable strain, asbestos metallic-woven sheeting may be used with advantage. One-ply sheets are suitable for all ordinary purposes. Pure asbestos is not affected by heat, water, or acids; for making joints, it is spun and incorporated with fine wire, and will stand a very considerable strain. Red lead combined with strands of asbestos can also be recommended. Twine, hemp, &c., cannot be recommended for high-pressure joints, as, owing to the extreme heat, they rapidly char away and leakage is the result.

Cement for Large, Coarse Steam Joints.—Mix two parts of finely powdered red lead with one part of very fine sand and one part of slaked lime. When required for use, mix some of the above with boiled linseed oil and apply quickly, or it will set hard and become useless. Make a thin joint, and mix only what is wanted for immediate use.

To Make a Rust Joint.—To make a rust joint that will stand heat, cold, or rough usage: Take 10 parts iron filings, 3 parts chloride of lime, and enough water to make a paste. After application let the joint thoroughly dry before use

Cements for Steam and Water Joints.—Ground litharge, 5 lbs.; plaster-of-paris, 2 lbs.; yellow ochre, $\frac{1}{4}$ lb.; red lead, 1 lb.; hemp, cut into $\frac{1}{2}$ in. lengths, $\frac{1}{4}$ oz. Mix with boiled linseed oil to consistency of putty. Another: White lead, 10 parts; black oxide of manganese, 3 parts; litharge, 1 part. Mix with boiled linseed oil.

Anti-oxidation Paint.—Red lead, 8 parts; zinc in powder, 10 parts; dryers, 2 parts; linseed oil, 80 parts. Make as required and apply fresh.

To clean Brass Engine and Boiler Fittings.—Take oxalic acid, 3 oz.; rottenstone, 18 oz.; powdered gum-arabic, $1\frac{1}{2}$ oz., sweet oil, 3 oz., and sufficient water to make a paste. Rub the brasswork well with this, rinse with water, and finish with whiting and wash-leather.

Rules to find the Horse-power of an Engine.—Although the term 'nominal' horse-power is obsolete from an engineering point of view, it is still used commercially. I therefore give the following rules for ascertaining the nominal horse-power:—

For non-condensing engines: *Rule.* Multiply the square of the diameter of the cylinder in inches by 7, and divide the result by 80. For condensing-engines: *Rule.* Multiply the square of the diameter of the cylinder in inches by 7 and divide the product by 200.

To find the actual Horse-power of an Engine.—*Rule.* Multiply the area of the cylinder in square inches by the average effective pressure in lbs. per square inch, less 3 lbs. per square inch frictional allowance; and by the speed of the piston in feet per minute. Now divide the product by 33,000, and the quotient will be the actual horse-power.

To find the Brake Horse-power of an Engine.—*Rule.* Multiply the circumference of the brake circle in feet by the number of revolutions per minute, and by the suspended weight in pounds; divide by 33,000; or C = circumference in feet of brake circle; R = revolutions per minute; W = weight suspended. Then

$$\text{Brake horse-power} = \frac{\text{CRW}}{33{,}000}.$$

CHAPTER IV.

EXPLOSION OF STEAM BOILERS.

Much has been written as to the causes of steam-boiler explosions, and many 'clever' but far-fetched theories as to mysterious agencies at work have been advanced by quasi-scientists and others—such, for instance, that there exists in steam boilers a mixture of air and more or less carburetted hydrogen, which is fired by an electric spark, produced through the friction of globular steam in narrow passages; but the author being no believer in mysterious agencies, has nothing fresh to propound in this direction. Looking at the question practically, he thinks that the explosion of steam boilers can generally be attributed to one of the following causes, although there may be other subsidiary reasons leading up to them :—

1. The use of worn-out boilers.

2. From over-pressure, or a pressure in excess of what the boiler is calculated safely to bear.

3. From the use of boilers of defective design or construction, or made of inferior materials.

4. From shortness of water and over-heating.

5. From collapse of flues.

6. From incrustation.

7. From corrosion.

8. From improper setting of the boiler, so as not to allow of thorough internal and external examination &c,

9. From allowing the flame of the fire to constantly impinge against the boiler plates at one spot.

10. From neglect of needed repairs.

11. From defective or wedged safety-valves, choked water-gauges, or improper position of feed-water inlet &c.

12. From extraneous causes, such as lightning or fire.

13. From faulty or improper method of repairing.

14. From unequal expansion weakening the steel or starting leaks at the seams, rivets, &c.

15. From mismanagement, arising from ignorance, neglect, or carelessness.

Although the above is probably a tolerably complete list of the chief reasons that give rise to boiler explosions, it is often a matter of extreme difficulty, in fact I may say impossibility, to trace the explosion to either one of these heads. After the explosion has occurred, what do we find in many cases? Simply a wrecked building and some rippeo sheets of iron. The evidence to be obtained is often meagre and unreliable, so the matter has to resolve itself into one of pure conjecture.

1. Referring to reason **The Use of Worn-out Boilers**, there is little doubt that large numbers of second-hand boilers are sold by 'engineers,' dealers, and others that are extremely dangerous to use—in point of fact are only fit for the scrap heap. In a recent case which came under the author's notice, a boiler was bought 'cheap,' without inspection, and sent to London to work a sawmill—where the duty is especially severe, by the way. The writer happening to visit the establishment on other business, was asked to look at it, and with very little trouble succeeded in knocking holes through several plates, which were reduced in places to something like one-sixteenth of an inch in thickness. Consequently, had this boiler been set to work, a disastrous explosion would probably have been the result.

The only suggestion the author can make in this connection is that both buyers and sellers of worn-out boilers be made criminally liable wherever possible.

2. **Explosions from Over-pressure.**—These arise from pressing a boiler beyond its capacity, or, in other words, trying to make a small boiler do duty for a large one, a practice not by any means unknown. This constant excess of pressure over what the boiler has been designed to bear has a gradually weakening effect on the plates, strains and opens the seams, and sets up leaks which often develop into fractures. It therefore follows that, to secure immunity from accident under this head, a boiler of ample capacity for the work to be done should be used, and it should have a large margin of strength, or a factor of safety of, say, 5 to 1 over any legitimate working strain that may be put on it—to allow for deterioration of various kinds. Wire-drawing the steam should never be resorted to, as it causes a boiler to deteriorate rapidly, and may be dangerous. We have known of several cases of explosions from over-pressure in a series of boilers produced by the dangerous practice of making one safety-valve do duty for several boilers, and by closing a stop-valve placed between one of the boilers and the safety-valve.

A dangerous form of over-pressure, or, I may say, suddenly applied pressure, may be set up by suddenly closing a stop-valve, causing an instant recoil of the steam, and various accidents have undoubtedly arisen from this cause.

3. **Explosions from the Use of Boilers of Defective Design or Construction, or made of Inferior Materials.**—There is little doubt that a large number of boilers are in use that are defective in design or construction, or both; such, for instance, as the want of proper staying, injudicious arrangement of seams, manholes, mountings, &c., and the use of faulty or inferior materials and workmanship.

It is without our province here to discuss the question of steam-boiler design and construction, although we give elsewhere, for the use of non-technical readers, a few of the points to be desired in a good steam boiler. With reference to bad workmanship and the use of inferior materials, excessive competition and unfair trading has much to answer for in this connection. The avarice of 'cheap' buyers is also to blame for this, as they will not be convinced that to secure a safe and good boiler they must be content to pay a fair price for labour and materials, but are content to daily risk the lives of their workpeople. Where human life is at stake, we are of opinion that it should be compulsory with makers to use only materials and workmanship of the highest class.

4. **Explosions arising from Shortness of Water and Overheating.**—A large number of explosions, collapse, &c., have been traced to deficiency of water, arising through the carelessness of the attendant, or from the feed-pump, pipes, or valves becoming choked or out of order. We have recently come across the case of an explosion of a vertical boiler from overheating of the fire-box, due to shortness of water. This arose primarily from the check-valve being placed in an improper position, viz. below the crown of the fire-box. The check-valve being out of order, the water was thus able to drain away and leave the fire-box unprotected. The check-valve should in all cases be placed several inches above the fire-box crown, so that if the water did drain, the box would still be protected; had this been done it is probable this accident would not have occurred. A false level of water is sometimes shown in the water-gauge, from the partial or entire closing of the bottom waterway by scale or dirt. The false water level in many cases may be accounted for through the condensation of the steam in the upper

portion of the glass running down, and, being prevented entering the boiler by the scale, it remains in the gauge-glass and thus shows a false level. In the winter this condensation is, owing to the cold, of course more rapid, and especial care should therefore be taken in constantly testing the gauges and water-cocks to see that they are quite in order and perfectly clear. We can recommend cocks packed with asbestos, as they are easy to turn and yet are free from leakage. Care should be taken that boilers are set to a dead-level, or errors as to the water level may arise from this cause. An excellent combined water-gauge and water-alarum is now made, and as it has no complicated parts, and should be certain in its action, its use can be recommended. This can hardly be said of some of the low-water alarums now made, containing stuffing-boxes, springs, levers, &c., which from their complications are very liable to stick when wanted. In all low-water alarums, to obviate sticking, it is important that the parts should be free to expand. In large boilers the old-fashioned float, which should not be of too light a construction, is not by any means to be despised, and fusible alloy plugs, if carefully looked after and renewed, are also useful. In large establishments two feed-pumps, or a feed pump and an injector, should be used for the water supply, as in case of the failure of one of them the whole works are not laid idle.

Although overheating from shortness of water may not in many cases absolutely cause an explosion at the time, it undoubtedly lays the foundation for one by damaging the quality of the steel by crystallising it and rendering it more brittle; in other words, burning the 'nature' out of it. This is more particularly the case when boiler plates, having been overheated, are rapidly cooled. Sometimes overheating may occur through the bursting of a tube or a serious leakage; in these cases the attendant should draw the fires at once. A very fruitful cause of overheating and burning the plates is from allowing incrustation and deposit to accumulate about and around the fire-box and furnace ; this causes cracks and leaks at the seams, rivet-heads, stay-bolts, &c., and may ultimately lead to a disastrous explosion.

A false water level may sometimes be occasioned, where much steam is drawn from the boiler, by a modified form of priming.

If fusible plugs are used, and are neglected and allowed to fur over, they are worse than useless, as the boiler-owner is relying on them in case of accident, and, should the boiler become overheated, they may refuse to act. There is little doubt that the constant heating and reheating of the plugs gradually hardens and chemically alters the nature of the metal of which they are made ; they should, therefore, be examined and renewed periodically. To prevent fusible plugs furring up, it is a good plan to make them, say, one inch longer than is necessary, and let them project into the boiler ; the scale is thus prevented covering up the plug entirely. Plugs should never be less than one inch in diameter.

5. **Explosions arising from Collapse of Flues.**— Collapse of boiler flues can hardly be termed an explosion in the strict sense of the term, although the result is often disastrous. Collapse arises in some cases from a partial vacuum within the boiler in conjunction with a pressure of steam forcing down the top and sides of the flue ; it is usually attended by shortness of water and heated plates over the crown of the furnace. Of course large ill-proportioned or improperly strengthened flues are more liable to collapse than properly designed ones. To avoid collapse, the tubes of Cornish and Lancashire boilers should in all cases be fitted with strengthening rings, and especial care be taken that the boiler is kept free from incrustation over the crown of

the furnace, and a fair level of water is maintained to prevent the chance of overheating and weakening the boiler plates (see page 72).

6. Boiler Explosions arising from Incrustation. The nature of the scale or sediment thrown down in steam boilers varies to a greater or less extent with each sample of water, but, as a rule, it consists chiefly of carbonate or sulphate of lime, with magnesia and gypsum. These form a more or less hard scale on the boiler plates, and, as heat cannot penetrate through it rapidly, a large loss of fuel is the result; at the same time, the boiler plates are much more liable to overheat and burn and crack, hence the chance of explosion is considerably increased. It may not be out of place here to draw the reader's attention to the necessity, from an economical point of view as well as for safety, of keeping boilers thoroughly clean. It has been tolerably well proved that a hard scale of one-sixteenth of an inch in thickness causes a loss of heat of from 15 to 20 per cent., which increases rapidly with greater thicknesses. If the feed-water is very bad, it may require to be softened by a chemical process before using. The Porter-Clark or Howatson lime processes are simple and effective. In all cases we can recommend the employment of a good feed-water heater and filter, but whatever is used, boilers should be blown out regularly and cleaned by hand. Many remedies for preventing incrustation are advertised; some of these are impostures and some positively injurious to the boilers. It may be as well here to premise that a remedy that may answer well with one sample of water may be comparatively useless with another. Steam-users, therefore, who are troubled with incrustation should in all cases have the feed-water analysed with a view to provide the proper remedy. A vast number of materials have been recommended, amongst these oak and other barks, logwood, &c. These undoubtedly have an effect on carbonate of lime, but their constant use is injurious to the boiler plates, owing to the tannic acid which they contain. For a like reason any remedies containing acids should be avoided. An extract made from the leaves of the eucalyptus tree has latterly been introduced into this country from the United States, and, from what we have seen and heard of its properties, we think there is little doubt it would be successful in many cases. It is a thick green-coloured fluid, and appears to have no ill effect whatever on the boiler plates. When introduced into a clean boiler it seems to act as a slight varnish on the face of the plates, and prevents the adherence of incrustation. The action of eucalyptus is not rapid on boilers already incrusted, especially with hard scale; but that it has a greater or less effect on all kinds of scale is sufficiently well proved, although as to what is the active agent contained in the extract is not very apparent, an analysis giving the acid reaction shown by the fluid as ·127 per cent. of sulphuric acid—an almost inappreciable amount.

Refined petroleum in small quantities will be found very useful in water containing the different forms of lime; soda ash is also recommended for the same purpose. For water containing gypsum, barium chloride has been used with success. The author has used tannate of soda for some years, and, although its effect will of course vary somewhat on different samples of water, for general purposes he can strongly recommend it, as it is, unlike many advertised nostrums, cheap, tolerably effective, and has no injurious effect on the boiler plates. With some samples of water several remedies may be combined with good effect. Hydrate of soda has been used with considerable success in waters containing silicates and some kinds of salts. Mud-catchers or drums are useful in limiting the deposit of incrustation over the fire-box. The amount of soda or other remedies to be used can only be determined with accuracy by an analysis of the water. In cleaning boilers for the first time notes should be taken as to what places the incrustation is chiefly found in, its nature, and the amount of it; this will be useful in devising a remedy. In cases of bad feed-water and incrustation, the blow-out and scum taps should be opened two or three times a day, and the water blown down, say, a quarter of an inch. Boilers with a sluggish circulation will incrust quicker than those in which the circulation is rapid.

Whatever remedy is employed to loosen the incrustation, when it has had time to act the boiler should be opened and thoroughly cleansed. Should an accumulation of sediment be allowed to collect, burnt boiler plates will almost certainly follow, if nothing more serious. Severe accidents have been attributed to the boiler being made very hot and, the scale becoming detached, a large quantity of highly elastic steam was instantly formed by the water coming in direct contact with the hot plates.

7. Explosions arising from Internal Corrosion. The question as to the origin and prevention of corrosion in steam boilers is one that has puzzled engineers for many years, and even now very little can be said with *certainty* on the subject. The origin of internal corrosion is little understood, and it has been attributed to a great number of causes; it is very erratic in its action, and will attack a boiler or pipes in one place and leave another quite free. The seams, tube ends, and neighbourhood of rivet-heads are, however, its favourite points of attack. When corrosion has once set in it is difficult, if not impossible, to control it. There is no doubt that impurities in the feed-water, in the shape of some deleterious acid or mineral matter, are the primary cause for active corrosion. 'Grooving' is generally attributed to the buckling action of the plates, combined with that of corrosive feed-water. To overcome this, joints are generally made with double butt-straps instead of overlap. Oxide of iron, which forms a reddish scale, is generally held to be one of the agents by which corrosion is set up; another and more dangerous is sulphuric acid, often found in mining districts and which often causes rapid corrosion. This can be separated by heat, on account of its specific gravity, which is 1·844; to do this the feed-water requires to be heated to a temperature of at least 260° Fahr., when a chemical separation takes place; and if it is afterwards filtered through, say, wood charcoal a mechanical separation of impurities is also effected. This may be done in a variety of ways as already explained; if the water contains a moderate amount of acids, the action of these may be chemically counteracted by the admixture of an alkaline. Soda is largely used for this purpose, but care must be taken that only the right amount is added; this can only be ascertained with certainty by analysis.

Another remedy used for the prevention of corrosion and incrustation is zinc; its efficacy, however, has been somewhat disputed, and there is little doubt that its effect varies considerably with different samples of water. Some experiments have recently been made in Belgium in which the results have been decidedly in favour of the use of zinc. The boiler was a tubular one, and a helix made of zinc was inserted in each tube. The feed-water was very bad, and at the end of five weeks, although the sediment in suspension was constantly blown out, the helices had collected a considerable deposit of the following composition:—

Zinc oxide, 37·15 per cent.; peroxide of iron, ·35; lime, 20·66; magnesia, 2·24; sulphuric acid, 31·38; silica, 1·60; carbonic acid, 6·45.

From what I have seen of the extract of eucalyptus leaves, I think it has a tendency to prevent corrosion as well as incrustation by forming a thin kind of varnish on the face of the plates, and so protecting them from the water. No positive remedy for internal corrosion has yet been discovered ; the chief preventive, however, is the purification of the feed-water before it enters the boiler. Occasionally a very thin layer of incrustation may be used with advantage in protecting the boiler plates from bad feed-water, but this should never exceed, say, $\frac{1}{64}$ of an inch. If boilers partly filled with water are allowed to remain at rest for some time active corrosion may be set up. It has been noticed in boilers where extensive repairs have been made with a different brand of steel to the original construction, that corrosion has attacked one lot of plates and left the other free. The theory of this is, that the one iron is chemically different to the other, and contains impurities that are more readily acted on by the corroding agents. Leakages from joints and seams &c. are a fruitful cause of external corrosion, and hence the necessity for careful inspection. External corrosion may be caused by an accumulation of soot in the flues or tubes, if allowed to get moist ; this arises in the case of coal fuel from the presence of sulphuric acid in the soot, and with wood fuel pyroligneous acid is often found in considerable quantities. The amount of acid found depends, of course, on the nature of the fuel, but with boilers in a damp situation active corrosion may be set up by these means.

In iron and steel works boilers are now often heated by the waste gases from the furnaces, and the sulphurous elements in them become condensed to a certain extent, and in the case of leaks or other moisture penetrating extremely active and rapid corrosion may be started, and should the boiler not be periodically and carefully inspected an explosion may be the result, as the plates soon become dangerously thinned.

The feed-water, if likely to be of changeable quality—as that taken from a river, for instance—should be tested for acid with litmus paper, say, once a month. This is a very simple matter, and more than one boiler explosion has been traced to the use of river feed-water containing acid discharged from works. These would probably have been prevented had the boiler-owners taken the trouble to test the water.

The principal remedy for internal corrosion is without doubt the purification of the feed-water. External corrosion, with a proper system of inspection, should be more under control; it may arise from leakage caused by undue expansion, improper repairs, &c. It is important that drippings from the roof &c. are not allowed to penetrate to the flue top or boiler. If it is a necessity that the boiler be worked in a wet or damp place, it should be painted with oxide paint and cased in sheet lead.

8. **Explosions from improper Setting of the Boiler.**—All boilers should be set so as to admit of a thorough internal and external examination. Boilers are sometimes set in almost solid brickwork, consequently external corrosion may be going on to a serious extent without detection, the end being an explosion. Mid-feathers or brick supports are to be avoided, as corrosion often takes place down the centre of the boiler resting on the brickwork. This may be avoided by supporting the boiler on either side and leaving its bottom clear for examination. Should a mid-feather be used, openings should be left in the brickwork at the boiler seams, so as to admit of their inspection.

In covering a boiler with a non-conducting composition to prevent radiation of heat, the author recommends, wherever possible, that the material is fitted in a light framework and put on in sections, so as to admit of their periodical removal for inspection; also the use of fire-clay lumps, with openings at the seams, for resting the boiler on in preference to ordinary brickwork. If a boiler is not truly and properly set and supported, very considerable strains on the rivets and joints are set up, which may tend ultimately to leakage or fracture. This is particularly the case with long boilers. After boilers are fixed they should stand a week to allow the masonry to harden. On getting up steam only a small fire should be kept up for the first day or two, so as to warm and dry the pipes and brickwork, and only a low head of steam should be used at first.

9. **Explosions arising from allowing the Flame of the Fire to constantly impinge against the Boiler Plates at one Spot.**—The above reason may appear to be rather a far-fetched one, but the author has known many cases of burnt fire-boxes from ignorant and bad firing, and there is little doubt that many accidents have arisen from the same cause. If a hot fire is allowed to constantly impinge at one spot, it is only a question of time for the steel to become weakened and crystallised. This arises from the fact that the steel cannot transmit the extreme heat—developed in a very limited area—fast enough to the water. Should the fire hit against a seam, this evil is of course much intensified owing to the double thickness of metal and the break or space between the plates. The same evil, arising from slow transmission of heat, occurs if the plates are covered with incrustation. If, owing to malconstruction, much heat is thrown against a plate above the water line an accident will very soon occur should the evil remain undetected.

10. **Explosions from Neglect of needed Repairs.**—It cannot be denied that explosions have arisen from the above cause or the putting off of repairs 'till a more convenient season,' which may never arrive. In busy seasons, to save time, leaks are often rusted up, or 'soft'

patches are put on when the whole plate should have been cut away and the boiler properly repaired. The author need hardly point out to steam users the extreme danger of this proceeding, and observe that the strength of a boiler is only the strength of its weakest part. It may be in capital condition with the exception of this one weak place, and give the user a feeling of false security, the final consequence of which may be a disastrous accident. From an economical and every other point of view, needed repairs, however slight, should be thoroughly executed by a skilled man immediately any weak place or defect is discovered. It is an old saying that 'delays are dangerous;' they are particularly so when applied to the repair of steam boilers.

11. **Explosions from Defective Safety-valves** may arise from the sticking of the safety-valves, the wedging of the safety-valve through the ignorance or foolish bravado of the attendant, or from trying to make a small boiler do duty for a larger one. Referring to safety-valves, there is little doubt that many inefficient ones are in use, and some of these of an area altogether insufficient for the work they have to do. On large boilers two safety-valves in all cases should be employed. In preference to a single large one, the author can recommend the use of a group of small pendant deadweight safety-valves, as these at a given pressure require a less load, and at the same time will give a larger lip opening for the escape of the steam. Lock-up safety-valves are occasionally used, but with a careful attendant they are unnecessary and in a measure tend to defeat their own ends, as unless they can be constantly tested they may be found stuck, and consequently useless when wanted. Some are, however, now constructed that they can be readily tested, but no extra weight can be put on the valves. Whatever form of safety-valve is used, the area and lift of the

valve ought always to be in proportion to the steam pressure and rate of out-flow for safety. Ordinary lever safety-valves will stick from a variety of causes, such as too tight a fit of guide-feathers in the valve-chamber, from dirt, or from the accidental bending of the lever or guide-spindle. Safety-valves should not under any circumstances be placed on steam pipes or places where communication can by any possibility be cut off from the boiler by closing a stop-valve or what not. This arrangement has been the cause of several explosions.

If the engine has to stop for a time the safety-valve should in all cases be tested, as many accidents have arisen from a gradually accumulated pressure, the valve, when wanted to relieve the boiler, being found jammed fast, or if the safety-valve be of an area inadequate to the rapid discharge of the accumulated steam a similar result may follow. (See notes, pp. 20 and 22.)

12. Explosions arising from Extraneous Causes such as Lightning or Fire.—Explosions arising from the above causes are not numerous, but they do occasionally occur. The cost of fitting a lightning-conductor to a chimney is small, and it is undoubtedly a protection.

Copper rod or copper rope fixed with joint irons supporting vitreous bearings is perhaps the best arrangement. Care must be taken in fixing that there is no break in the rod, and it should project, say, 3 or 4 feet above the top of the boiler chimney. The rod should be fixed on the outside of the chimney and carried well into the ground, terminating in two or three branches running into a well or drain or other water.

13. Faulty or Improper Method of Repairing.—It is important that, when repairs are needed, they are only entrusted to skilled hands used to boiler work; this is not always done, and there is little doubt that explosions have arisen through faulty or improper repairs. We have known a case where weak brittle steel of a different thickness was used, consequently unequal expansion arose and leakage and fracture was the result. Again, when rivet-holes do not correspond to each other, drifting and caulking are often indulged in to a considerable extent, and to stop the weeping when steam is raised various substances are introduced into the boiler. If any doubt arise as to the execution of repairs, it is undoubtedly advisable to have the opinion of a competent engineer or boiler inspector. Leaks may be started by flooding the boiler with cold water; the rate of feed and height of the water level should in all cases be carefully considered. A hot-water feed is much preferable to cold. When patching a boiler bolts should never be used in the place of rivets, and if a patch is required in the fire-box let it be of good size; small patches are as a rule unsafe, as the iron round them would usually be thinner than the patch. A steel patch should never be put on an iron boiler, and, if possible, plates of a similar brand and quality to those in the boiler should be used. Care should be taken that the patch is of the same curve as the rest of the plate. With the object of hiding the patch, the author has known cases where the new iron has been dovetailed in flush with the other plates and fastened with taper screws let in diagonally, red lead being used to make the joint; this arrangement, he need hardly say, is both dishonest and (unless carefully done) very unsafe (see p. 40).

14. **Explosions from Unequal Expansion weakening the Steel or starting Leaks at the Seams, Rivets, &c.**—The author is of opinion that the primary cause of not a few boiler explosions is the unequal expansion

of the parts which gradually weakens the boiler plates and seams, straining unduly the rivets and joints. This may be caused through faulty construction, poor circulation of the feed-water, large feed supply of cold water, cooling down too rapidly, incrustation, &c., and we have known of more than one instance of boilers gradually fracturing from being placed in a windy and exposed situation without adequate protection. Even with well proportioned and constructed boilers it is important that steam is raised very gradually, so that all parts of the boiler may be warmed together; unless this is the case, one part of the boiler may be very hot and another part nearly cold; consequently the expansion is unequal and extremely detrimental strains are set up, and as this operation is repeated every day the boiler may become gradually strained and weakened to a dangerous extent. The furnace-tube or fire-box should in all cases be free to expand, and if ample provision is not made for expansion, the constant and extreme heat will very soon strain and bow the tube. It can hardly be denied that sufficient attention has not hitherto been given by boiler designers and makers to the question of unequal expansion; we have, however, recently seen a new departure in this connection which should give satisfactory results. In the plan we speak of the flue or flues of Cornish or Lancashire boilers are made up in a series of short lengths, with their ends enlarged in such a way that the end of one exactly fits within that of the next. Both these ends are drilled and rivetted, they admit of expansion and contraction, at the same time their efficiency as stays is not injured. The plates are bent perfectly cylindrical and welded; the ends are afterwards heated and enlarged. An additional advantage claimed for this plan is that the seams and rivet-heads are not in the line of draught, and therefore escape the intense heat of the gases as they pass through the flue.

Boilers are often strained and damaged to a considerable extent by improper position of the feed-pipe, which may allow cold water to come into almost direct contact with hot plates. In the best practice, the feed-water is introduced into Cornish or Lancashire boilers through the medium of a perforated distributing pipe placed some inches above the furnace crown and extended about one quarter of the length of the boiler. In vertical boilers the distributing pipe is usually placed slightly below the standard water-level. Back-pressure valves should in all cases be fitted. The whole of the above remarks apply with particular force where quick-burning fuel is employed, as in sawmills, where sawdust and waste wood are used ; as a considerable draught is necessary and the furnace doors have to be frequently opened, the constant inrush of cold air has a chilling and extremely detrimental straining effect on the boiler plates and seams. This is proved to a certain extent by the fact that, taking the world over, there is a much larger percentage of explosions in sawmills than in any other kind of manufactory.

15. Explosions from Mismanagement arising from Ignorance, Neglect, or Carelessness.—It cannot be denied that many explosions are traceable to the employment of ignorant and unskilled labour, a common day-labourer being made to do the duty of a trained man. This arrangement is criminal, and at the same time it is false economy, as a skilled man will get greater duty out of the fuel, burn less of it, and at the same time add much to the longevity of the boiler. We have known cases of fine new fire-boxes being burnt out in a few months through unskilled firing, the cost of which—to say nothing of the extra fuel consumed—would have paid the difference between skilled and unskilled labour for a very considerable time. Ten years ago the author wrote the following, which he cannot do better than repeat : 'We are of opinion that all engine men or stokers entrusted with such a weapon of destruction, or such a grand servant as a steam boiler, should be compelled to pass an examination and hold a certificate as to his competency to undertake the position to which he aspires ; this, without entailing hardship on anyone, would secure a more intelligent class of men and add much to public safety.'

Steam-boiler Inspection. — Steam-boiler inspection, unless it is thoroughly done both internally and externally, is often worse than useless, as it gives the boiler-user a feeling of false security. The following hints as to boiler inspection are not, of course, intended for professed boiler inspectors, but for those who in outlying districts, or in the colonies, have occasionally to undertake this duty. Before commencing your inspection see that the boiler is stripped, and that it and the flues are thoroughly clean and free from incrustation and soot. 1. Examine carefully safety-valve, float, steam and water gauge, and all the boiler fittings ; see that they all move freely, and are not cut away, so as to cause jamming or leakage. 2. Examine carefully the feed-valve and pipe, scum-pipes and blow-off cock. 3. Examine carefully, internally and externally, all seams, joints, and rivets for grooving, pitting, corrosion, or leakage. 4. Examine fire-box or tubes and tube-plates very carefully, and note any symptoms of burning, bulging, blistering, or corrosion of crown or side plates. 5. Examine carefully all stays and braces, stay-bolts, and rivet-heads for corrosion or leakage ; also examine flanged plates for cracks. Try these with a hammer for fractures. 6. Examine fusible plug, man-, mud-hole, and other joints. 7. Examine boiler seatings for dampness, leakage, or external corrosion. 8. If the boiler has been repaired, examine all patches foı corrosion or leakage. 9. Take samples of any incrustation you may find, and, should there be active corrosion, a sample of the feed-water for analysis. 10. In cases of considerable 'pitting,' to make certain of the thickness of the plate the safest plan is to drill it. In examining a boiler it is well to go about it systematically, taking notes as you proceed, and not fly from one part to another, as something may escape notice. Much may be gathered as to the condition of a boiler by careful sounding, but to be certain it requires both experience and an acute ear. Corrosion being the most destructive agent in rapid deterioration of boilers, in inspection it should always be borne in mind that, although it usually attacks the stay-bolts, rivets, and seams, it is most erratic in its action ; it is often found in most unlooked-for places. If there is any scale on the boiler, look for red streaks where the scale is cracked, as corrosion may be going on to a dangerous extent below the scale. If there is brickwork on the outside, be very particular in sounding the plates ; in all cases have the boiler stripped as much as possible, so that the seams, seating, and exterior generally can be thoroughly examined. In testing a boiler to determine a safe working pressure, hydraulic pressure will be found very useful, but should not by any means be relied on. It will usually show up leaks and weeping at the seams, but many cases are recorded in which boilers have withstood the hydraulic test and have exploded when under steam. There is little doubt the chief reason for this is that with the water test the pressure is gradual and uniform, and with steam the pressure is intermittent and various straining actions are at work. With the hydraulic test incrustation will often cover and protect deeply set corrosion, enabling the plate to withstand a very considerable pressure. If, therefore, the hydraulic test is applied, this should never prevent a thorough internal and external examination of the boiler. The author prefers to test a boiler whilst it is warm, say immediately after finishing work, as it is then expanded and in something like its normal working condition. He, of course, in this case uses warm water instead of cold. The boilers of portable engines may, in cases of emergency, be tested by the feed-pump attached to it, in fact some inspectors do this habitually. In certifying a working pressure for a boiler, especially an old one, leave a large margin of safety, as with a fierce fire in some cases it will take very few minutes to raise steam from a safe working to a bursting pressure. If a boiler has been repeatedly patched and repaired, and you have any doubts at all about it, condemn it. Hundreds, or even thousands, of boilers are in use—daily risking life—that ought to have been long ago on the scrap heap.

Preparation of Boilers for thorough Inspection. (1) Clean the boiler thoroughly, both inside and out, removing all incrustation, also ashes from the fire-box and ashpit and soot from the flues. (2) Remove boiler covering or brickwork that prevents inspection, more particularly at the seams. (3) Remove all man and mud hole covers. (4) Should the boiler attendant be aware of any weak places, fractures, leaks, or defective fittings, mark and call the inspector's attention to them. (5) Show the inspector samples of any incrustation taken from the boiler.

Compulsory Certificates for Steam-boiler Attendants.—The author has long been of opinion that where human life is at stake, as in the working of steam boilers, those that have the care of them should pass an examination as to their competency to undertake the work, and hold a certificate to that effect. A system of Government registration and granting of certificates of competency would be attended with very beneficial results to the attendants themselves, as well as to boiler-owners and the public generally, as it would give them some kind of recognised status. The granting of certificates has been tried, we believe, with distinct success in America, Germany, and some of the Australian colonies.

Compulsory Inspection of Steam Boilers.—The writer has long advocated the compulsory inspection of steam boilers. This, however, need not of necessity be undertaken by the Government itself, but certain well-established boiler insurance associations might be certificated and entrusted with the work. In case boiler inspection were made compulsory, the great increase of business would provide sufficient funds to enable the various associations to make a *thorough* examination of every boiler in the kingdom once a year. It is more than probable that if the work were undertaken by independent insurance associations it would be better done than if undertaken by a Government department, who would have no particular interest in the boiler, and would not be liable in any way if boilers did explode. Certificates as to safe working pressure might be granted to each boiler-owner, and orders issued to repair and make good any defects that might be discovered, and at the same time worn-out or unsafe boilers could be condemned. In France and Germany, Government boiler regulations are in force which place the manufacturer, as well as the boiler-owner, under certain restrictions as regards the construction and setting of the boiler in the first place, and afterwards as regards the periodical inspection and testing by Government inspectors. It is compulsory that the boiler be tested by the hydraulic test to at least double its working pressure before it leaves the manufacturer's premises. In Germany an external examination every two years is insisted on, and a complete internal and external examination every six years.

In this country at present nothing is done by the Government to prevent explosions, as far as land boilers are concerned, but an inquiry is ordered *after* a fatal accident has happened—a very good way of 'how not to do it.' I take it a Bill enforcing compulsory inspection and registration of steam boilers, and the granting of certificates to competent attendants, could be introduced without causing undue friction or interference with the rights of boiler-owners, and, by making use of the machinery of some of the present boiler assurance associations, at a very moderate cost.

Since writing the above, a Bill for the compulsory registration and inspection of steam boilers has been introduced into the House of Lords by the President of the Board of Trade, and has passed a second reading. It can hardly be called a complete Bill as it at present stands, the question of boiler attendants' certificates of competency, and various other matters of importance, not being dealt with.

CHAPTER V.

ADDITIONAL NOTES ON WORKING CORLISS OR 'TRIP' VALVE ENGINES.

A GREAT number of engines known under the generic term of Corliss or 'Trip' valve engines are now in use, but as these vary considerably in their valve, &c., arrangements, and general design, our remarks must not be considered as arbitrary. For high pressures and high expansions, compound or triple expansion engines are generally used. Very high pressure and high expansion, however, necessitate the employment of a larger and heavier engine; at the same time greater trouble is found in keeping it in good running order, as the joints and cylinder cover are more difficult to keep tight, and with very high pressures the packings are apt to burn, and the lubricant in the cylinder to carbonise. Notwithstanding, however, that the wear and tear on the engine is increased, the economy effected in coal usually more than counterbalances these drawbacks.

The chief disadvantage found in working Corliss engines arises from the generally complicated nature of the valve-gear used, and consequently its more or less frequent breakdown. Again, Corliss valves have not been found satisfactory for working with highly superheated steam, which of late has been considerably introduced into modern steam practice. The valves wear well and keep a very tight seat, but the gear is subject to disarrangement unless very carefully looked after and adjusted. This in some cases has arisen from the trip-gearing being made too light for the work, which usually consists in oscillating the valve about a quarter of a revolution between its opening and shutting by means of a trigger or trip of a valve lever, the shutting or being generally accomplished by a spring.

The chief forms of automatic cut-off engines are (1) those in which the travel of the valve is varied so as to alter the point at which the steam is cut off; (2) those in which the steam-valve spindle is released from the driving-gear that moves it to open for the admission of steam, whilst the cut-off is effected by 'dashpots,' weights, or springs, which close the valves, these latter being known under the general name of Corliss, or 'trip' valve engines; of this latter type we now propose to give a few notes.

The following may be stated as the chief advantages claimed for an advanced type of Corliss compound engine:—

1. The existence of separate steam and exhaust ports, which prevent the steam-port being cooled by exhaust steam during its exit from the cylinder.

2. The small clearance space necessary, owing to the shortness of the ports.

3. The small area of the valves, which reduces the total pressure on them, and minimises the power required to work them.

4. The automatic cut-off gear, which allows the engine to be regulated very exactly by the governor.

5. In the case of single wrist-plate engines the quick opening of the valves.

6. The thorough draining of the cylinder of horizontal engines.

Special forms of Corliss engines claim special advantages, but the above list is usually applicable.

In countries where fuel is dear, superheating the steam, so that it is admitted to the cylinder as dry as possible, has also been resorted to with beneficial effect, and a number of engines are running which consume no more than $1\frac{1}{2}$ lb. to $1\frac{3}{4}$ lb. of coal per indicated horse-power per hour, a result which will very rapidly return the increased first cost of the engine.

These engines, it need hardly be said, are of the most advanced type, and fitted with all recent improvements, such as angular adjustable pedestals, adjustable metallic packings for piston and valve-rods, oil-pumps for continuously lubricating the main bearings, sight-feed lubricators, etc.

A great advantage of the Corliss over the ordinary slide valve in horizontal engines is that no water can lodge in the cylinders and valve-chests, as the exhaust valves are placed in the bottom corners of the cylinders and rapidly drain them.

In the case of compound or triple-expansion engines, however, examine for water lodges the passages between high and low pressure cylinders, the bottom of exhaust-pipes, stop-valves, valve-boxes, and fit drain cocks if necessary.

In establishments where high pressures and high expansions are introduced, a really skilled attendant becomes an absolute necessity, the construction of the engine being more complex, and consequently requiring more careful attention. A really skilled man, however, is a good investment, and will very soon save the difference between his wages and that of a low-priced man ; at the same time the plant will be kept in a higher state of efficiency, and its longevity increased.

Steam Pipes and Fittings.—Steam pipes are now usually made of wrought steel. It is of the utmost importance that they be fixed elastically with a freedom to expand from cold to hot, say $\frac{1}{4}$-in. in every 10 ft. of length, and the neglect of this precaution has resulted in numerous accidents from steam pipes cracking. Drops and rises in the pipes must never be allowed, as they permit of the lodgment of water. For high piston speeds larger pipes are necessary. All flanged joints should be carefully machined and fitted. The writer can recommend corrugated copper gaskets for high pressure joints in preference to soft joints containing asbestos, rubber, &c., which more or less rapidly deteriorate.

In starting, open the junction-valve gradually for fear of 'water hammer' which is very dangerous. If when steam is turned on a cracking noise is heard in the pipes, water is being hammered about by the steam. Examine steam traps in pipes frequently for fear of sticking or choking. Examine for leaky valves which may go on for a long time without detection. Straight-way or gate pattern valves on steam and water-pipes for high pressures are to be preferred to globe valves.

A good arrangement is to give the steam pipe a continuous fall from the junction-valve on the boiler to a point below the engine cylinder where a steam trap and separator should be fitted, and the pipe then made to rise directly to the cylinder close to which the stop-valve should be fixed. Be sure the exhaust-pipe is of ample size and is free and straight; it should be cleaned periodically or back pressure may arise.

Air-pumps and Condensers.—Leakages in air-pumps and condensers are often difficult to detect, but if the degree of vacuum is much reduced they are to be suspected. The stuffing-box of cylinder, joints of pipes from cylinder to condenser, vacuum gauge connections, injection-valve, joint of foot-valve, condenser-pipes, &c., should all be carefully examined with a lighted taper. A fruitful cause of air-pumps breaking down arises from damaged valves, the constant hammering of the valves on their seatings, or from the valves, seatings, guards, or fastenings wearing and getting loose; these should, therefore, be constantly examined. If the air-pump is found to pound much a remedy sometimes employed is to fit a small pipe admitting a little air into the channel way.

Air-pump buckets will also sometimes jam through the packing-rings becoming worn and broken, or by the swelling of the wooden lagging on the buckets. With clean water a plain pump-bucket without any packing is now often used, and with dirty water a bucket packed with rope. The writer recommends that the air-pump be indicated occasionally, as serious defects can thus often be detected.

Care of Governor Gear.—It is of the utmost importance that the governor gear is sensitive and runs without undue friction, so as to admit instantly the right quantity of steam to meet the various changes in the load and keep the engine at a uniform speed. The working surfaces should, therefore, be carefully lubricated and examined from time to time to see that they are in good running order. The working parts should be made of hard steel, and never be allowed to wear slack, as this is a fruitful cause of 'hunting' and unsteady running of the engine. It is important that the oil used is of the finest quality and not given to gum or clog, or the gear will become sluggish.

Should the constant load on the engine be increased, and it is found necessary to speed the engine up to secure an earlier cut-off to meet the increased load, it is important that the speed of the governor is increased in ratio, or the running of the engine will not be so uniform. It is important when setting the governor and trip-gear that the latter is arranged to trip when the governor is at its lowest position, or live steam may escape down the exhaust. When an engine is started, and has made a few strokes, it is a good plan to slightly raise the governor so as to cause the cut-off to act, as there is less chance of taking water from the boiler, and it is an aid in getting a vacuum.

Care of 'Dashpots.'—Dashpots are usually operated through the medium of springs, but occasionally by steam or atmospheric pressure, an air-cushion being provided to ensure silent working. Care should be taken that they are kept in good working order, and always supplied with a sufficiency of oil to slightly retard the movement of the regulator when subjected to any fluctuation. Dashpots should be carefully covered so that no dirt can be drawn in between the moving parts. If the dashpots become sluggish it probably arises from a weak spring, from excessive cushioning, or from the oil getting thick and gummy. In this latter case clean out the dashpot and substitute soap and water for oil, and also ease the by-pass. Vacuum dashpots may become sluggish through a leaky piston, excessive cushioning, or from not being powerful enough for the duty.

Leaky Valves.—A very fruitful cause for loss of steam is leaky valves, and as these are not visible it may go on for a considerable time undetected. To test Corliss steam valves both valves should be released from their catches, when they will cover over the ports, the indicator-cocks should then be opened and any escape of steam past either valve will be shown.

In testing the exhaust-valves the engine should be barred round till one valve is closed, the engine should then be scotched, and the steam valve at the same end of the cylinder as the valve being tested should be opened. The stop-valve should then be opened gradually and steam turned on, the exhaust-pipe being watched for leakage. The second exhaust-valve should be treated in a similar manner.

In testing ordinary slide valves the engine should be barred round till the valve covers both steam ports; it should then be scotched, the cylinder-cocks opened, and the steam turned on; any steam leakage will be shown at the cocks and the exhaust-pipe.

Stop-valves are also liable to leakage, and to test them the junction-valve on the boiler should be closed and the engine barred round till one of the steam ports in the cylinder is wide open; the stop-valve should be closed and the steam turned on gradually at the junction-valve. The cylinder-cocks should then be opened and watched for an escape of steam.

Noises in Exhaust Valves, &c.—Noises or groaning in exhaust valves may be caused either from their being too tight a fit, and not allowing the oil or steam to penetrate between the surfaces, or, from what is more frequently the case, by the unevenness of the surface on the underside of the back end of each valve, this often showing in the form of bright smooth polished spots, quite free from oil, with corresponding spots on the valve seats. These spots should be carefully smoothed down with a file and properly lubricated, when the noises will usually cease.

Noises will also often arise when the engine is heavily loaded, or when a load is suddenly applied. This is often attributed to insufficient lubrication, but in many cases it is caused from water being drawn over from the boilers or steam-pipes with the steam. This can be proved by the quantity of water dripping from the piston-rod, valve-rods, &c. At the same time the water washes the lubricant from the working surfaces of the cylinder and valves, causing them to run dry ; hence the noise.

If the speed of the engine remains constant, no more lubrication will be required under ordinary conditions with a heavy load than with a light one.

Scoring of Steam Cylinders, Valves, &c.—The scoring and cutting of cylinders, valves, valve-seats, &c., may arise from a considerable number of causes, such as (1) insufficient lubrication, (2) improper or inferior quality of lubricant, (3) piston rings being set out too tight, (4) valve and valve-seats made of unsuitable material, and (5), perhaps most general of all, from sandy, gritty, and steely particles getting between the rubbing services.

Where the feed-water is dirty no doubt a quantity of gritty particles are carried into the cylinder by the steam itself. This is more particularly the case where hard scale is allowed to accumulate in the steam-pipe.

Again, when new engines are starting the core sand in the cylinder castings is not always entirely removed, and may do a considerable amount of damage before being detected. If tubular boilers are used, in raising steam great care should be taken in cleaning, especiallly if the tubes are bent. The same remark applies to portable and vertical boilers, which are difficult to keep clean round the fire-boxes and crowns owing to the cramped space.

Tightening Cotters.—Care should be exercised in tightening up cotter keys, and they should not be driven home by main force. If the key constantly becomes loose, it may arise from bad fitting, from the want of a deeper key, or from cross-bending or deformation in the rod or cotter. In such cases a new cotter should be fitted.

Lubricating Heavy Bearings.—In lubricating the bearings of large engines, in the most recent practice oil is pumped under pressure into the centre of each bearing. The most difficult bearing to keep properly lubricated is the crank-pin, and numerous devices have been introduced. The best with which we are acquainted is one in which a semi-solid lubricant is used. This consists of a stationary lubricator fixed with its delivery-pipe co-axial with the crankshaft. It delivers the lubricant through a cranked pipe to a central hole passing up the crank-pin, and thence by a cross-hole to the periphery or outside of pin. The cranked pipe revolves in a stuffing box in the base of the lubricator, and is fitted so as to allow for and neutralise any side play or jump in the crankshaft, and also for any longitudinal movement in it, and still run without leakage in the stuffing box. On this cranked pipe there is fixed an eccentric which operates a lever and pawl working on a ratchet wheel. On the ratchet wheel shaft is a worm geared into a worm wheel. The worm wheel has an internal thread through which passes the screwed piston-rod of the lubricator, which, in conjunction with a metallic piston, forces the lubricant through the bottom of the lubricator and along the cranked pipe to the crank-pin. By this means, at every stroke of the engine a small particle of the lubricant is put on the pin. The supply can be regulated, or the cup re-filled, when the engine is running.

Specification for a High-class Cylinder Oil (Willans).—A pure hydrocarbon oil, steam refined and charcoal filtered free from all acidity and from any admixture of light hydrocarbon oil or paraffin wax. The specific gravity to be ·897 at 60° F. The flash point to be not lower than 450° F. by the close test with Gray's apparatus, or 550° F. by the open cup test. The viscosity at 180° F. to be between 150″ and 170″ on Redwoods' standard apparatus. The loss of weight on exposure for four hours to a temperature of 350° F. not to exceed ·1 per cent., and on a further exposure of twenty-four hours, no observable change to take place in the appearance of the oil.

Packings for High Pressures.—After consider able experience for high pressures of steam, the writer prefers metallic packings for pistons and valve-rods to any other, as they will wear much longer and require less attention than any fibrous material. It is a *sine qua non*, however, that the rods are in perfect order, and the packing very carefully fitted in the first instance; and it should always be self adjustable to the movements of the rod. In working, if the piston is allowed to wear sufficiently, it will bring the piston-rod out of line, and quickly wear out the packing, and sometimes the rod itself will wear flat.

In large engines metallic piston packing, fitted with a bull-ring adjustable by set screws, is often employed for keeping the piston central. The piston should occasionally be turned round on its rod as it and the cylinder wears, as this will equalise the wear on the packing rings. These remarks apply also in a less degree to valve-rods, as, should the valve be allowed to wear and cause the valve-rod to travel at a slight angle, considerable side pressure is put on the packing.

CHAPTER VI.

FORCED OR INDUCED DRAUGHT.

The writer being often consulted as to the smoke nuisance and defective combustion generally, and as to the advantages and disadvantages of forced draught, a few remarks on the subject may be of interest.

Natural or chimney draught is, of course, still most generally employed, but in many cases—from improper design, height, proportion of the chimneys, and other causes—it is in many cases the reverse of satisfactory in securing effective combustion suited to the high pressures of modern boiler practice.

This being so, what is known as forced draught has of late been largely introduced, and there is no doubt that when judiciously applied a much more effective combustion is secured with a less consumption of air, and consequent waste of heat.

Forced draught is usually produced in two ways (1) by means of a fan, (2) by means of a steam jet. This artificial or forced draught is of two kinds, viz., forced draught, in which the air is forced through the fire from under the fire bars, or suction draught, which is similar to natural draught, and is usually produced by a steam jet drawing the air from above the fire bars. Unless there are a number of boilers steam jet draught is well suited for general purposes, as it is less costly to instal and keep up, and there is less chance of a breakdown.

If properly proportioned and applied, the amount of steam used is very small, and the rate of combustion largely increased. At the same time it may be as well to say that induced or forced draught does not really mean—as is often supposed—forcing and consequent deterioration of the boiler. With forced draught combustion can be effected with a less quantity of air than with natural draught, but a greater area of heating surface is necessary. The amount of heating surface required to secure the best results depends on the nature of the fuel used, rate of combustion, &c. ; every case, therefore, should be judged on its merits.

Other advantages are that inferior fuel may be used, and so large a boiler for a given power is not necessary. Again, where mechanical stoking is in use, the constant rush of cold air when the furnace door is opened for hand stoking is avoided, and a much higher temperature and rate of combustion is secured, enabling coal or coke breeze, sawdust, &c., to be burned with a facility that is impossible with ordinary natural draught.

In most saw mills, for instance, small coal, sawdust and planing machine waste is the general fuel, and this can be very effectively burnt with forced draught, the higher rate of combustion making up for the poor evaporative value of the fuel, and a constant head of steam being kept up without difficulty, the forced draught being unaffected by winds, down draught, &c., and the temperature in the combustion chamber and flues being practically constant, the injurious effect of sudden expansion and contraction is done away with.

The chief obstacle found in applying induced or forced draught successfully was the difficulty of applying it equally over the whole area of the fire. Perhaps the most successful system of steam jet draught is that which acts through two or more pipes placed beneath the fire bars, the hot air being forced thereby through the burning fuel, and if this is combined with a jet admitting hot air from the bridge and over the surface of the fire, the various gases are mixed at a high temperature, and efficient combustion secured.

In applying this system the ashpit is closed, and thus a fairly equal pressure over the whole area of the fire can be maintained, and without imparting too great a velocity to the hot gases which would rob the boiler of part of their heat.

With this system hot air only is admitted both below and above the fire bars, and the constant rushes of cold air and consequent reduction of temperature through frequent opening of the fire door or grid are obviated. The fire bars used and the air spaces between are made very narrow, and from the pressure in the ash pit the highly-heated air is forced between them over the whole area of the fire, but the action of the steam keeps the bars from burning.

To ensure perfect combustion and prevent smoke, the writer is strongly in favour of admitting hot air to the combustion chamber from both below the fire bars and above the fire. Cold air admitted from the door or grid is useless for combustion till it becomes heated, and to do this considerable heat is used that might do useful work, and in the case of natural draught a large amount of heat is carried directly to the chimney stack. It cannot be too often urged that an excess of cold air admitted to the furnace beyond what is absolutely required for combustion is so much loss of fuel. This is under ordinary stoking and conditions a very fruitful cause of loss, as often two or three times the amount of air is admitted that is required: at the same time unequal expansion and contraction is set up which is a very fruitful cause of boiler deterioration, especially in cold and draughty situations, when the furnace temperature will often vary as much as 1,500° Fahr. in a very short time.

The steam used should be as dry as possible, and may be superheated with advantage.

It may be urged that by the introduction of forced draught a considerable amount of steam is used; this is not so, as with a well-designed and applied apparatus the steam consumption should not exceed 3 per cent. of the power of the boiler, and this is more than recouped by the various advantages that are secured.

As regards the economy of using forced draught, it is generally conceded that, when it is properly applied to a boiler of favourable design, a saving of from 10 to 15 per cent. may be effected.

Advantages Claimed for Forced or Mechanical Draught.— The chief advantages claimed for forced draught may be roughly stated as follows:

1. Costs less for installation than the chimney.
2. It is capable of burning very low grade fuels.
3. There is more complete utilisation of the waste heat of the flue gases.
4. Can more readily meet sudden demands for extra steam.
5. Is independent of down draught or atmospheric changes, &c.
6. Can be adapted to almost any circumstances either instead of or as an auxiliary to a chimney shaft.
7. Can be automatically controlled so as to maintain a constant steam pressure.
8. The prevention of smoke.
9. The constant entrance of cold air to the fire-box is avoided.

CHAPTER VII.

FIXING CORNISH AND LANCASHIRE BOILERS.

Although during late years considerable attention has been given to what may be called the scientific setting of boilers, large numbers are still in use in which, from improper or inefficient fixing, a considerable unnecessary daily loss goes on.

It need hardly be remarked the object to be aimed at in setting boilers is the extraction of the greatest possible amount of heat from the furnace gases before they are allowed to pass into the chimney, and the more effectively this is done the better the setting.

In setting boilers the chief points to be desired are :—

(1) To obtain the greatest possible amount of heating surface.

(2) The flues should be readily accessible for examination and cleaning, and be entirely free from air leakage.

(3) The boiler should be mounted on fire-clay seating blocks that conceal as little surface of the plates as possible, and leave the seams capable of ready examination.

(4) The efficient distribution of the hot gases.

(5) A good draught.

(6) A minimum loss of heat from radiation.

To obtain the greatest amount of heating surface, and prevent defects being concealed, in recent practice wide seating blocks, mid-feathers, &c., have been done away with, and curvilinear seating blocks, flue covers, crosswall and partition blocks of fire-clay have taken their place, as shown in illustration (fig. 1).

From this it will be seen that the curved surface of the seating blocks on which the boiler rests (A) is of the smallest possible area, and permits a ready examination of practically the whole boiler. At the same time, any water running down the side of the boiler has no place for lodgment between the seating and the plates, and any soot can be

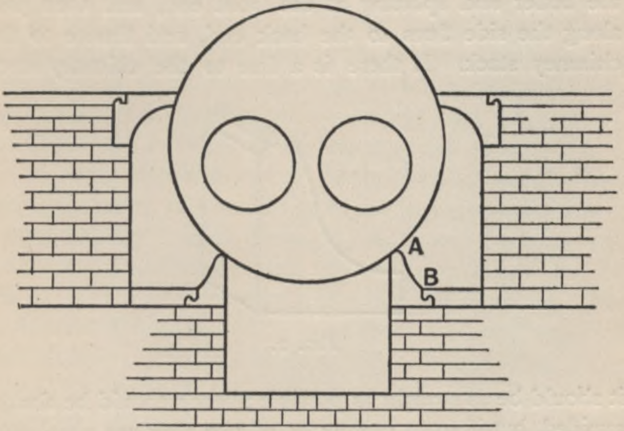

Fig. 1.

readily brushed away. To allow of a ready examination of the circular seams the setting blocks at these points can be made movable, and the longitudinal seams should be kept clear of all brickwork.

Fig. 2 shows a patent asbestos-cushioned boiler seating block. In this block a narrow flexible cushion of asbestos is inserted between the boiler and the seating, and the weight of the boiler compressing the cushion forms a sound joint and prevents leakage from the flues. Seating blocks are now often made to interlock with connecting slabs, which line the bottom of the flues as at B. It is important that the side-flue covers are carefully fitted and are entirely free from air leakage; in recent practice these covers are made to lock-joint or overlap each other at the sides, and are also made liftable so as to let in daylight, allowing the boiler to be more readily inspected.

Flues should be arranged so that the hot gases and products of combustion pass first of all under the bottom of the boiler and splitting at the front end, and then pass along the side flues to the back end, and thence to the chimney stack. If there is a flue to the chimney stack

FIG. 2.

it should be as straight as possible; bends should be always avoided, but if from exigencies of site they are absolutely necessary they should be made as gradual as possible. All flues should be faced with fire-brick and set in fire-clay, and should be of sufficient size for a man to pass through for examination, cleaning, or repairs to the boiler. Small flues are a mistake, as they cause the gases to travel too rapidly, consequently they fail to give up a fair proportion of their heat. As soot is a bad conductor of heat, care should be taken in setting that there are no ledges on which it can lodge, and with this object in view, and to allow the soot to fall to the bottom of the flues, the back edges of the bearing blocks are often made square and brought right up till they touch the boiler-plates. The flue-covers should be flat on the top, and come flush up to the boiler-plates, level with the crown of the internal flues, leaving no crevices for an accumulation of dirt.

A suitable brick-lined chamber should be provided for the blow-out tap, pipe, and bend, this latter in the best practice being made of copper, which, owing to its flexibility, allows for the necessary expansion and contraction of the boiler.

In fixing a Lancashire or Cornish boiler the front end of the boiler should be slightly lower than the back, say from 1 in. to $1\frac{1}{2}$ in., and care must be taken that the longitudinal seams do not rest on the seating, and, if necessary, the size of the flues can be slightly modified accordingly.

It is very important that all flue brickwork should be kept in perfect order, as, should there be a leakage of air, heat is wasted and the draught damaged; or, should the brickwork be allowed to get damp from any cause, corrosion may be set up, and if undiscovered may become dangerous. The boiler and all flues should be carefully cleaned and inspected periodically. Cast-iron frames with air-tight flue doors should be built into the front cross-wall. The bottom of the front end-plate should be about 2 inches above the floor level, to avoid corrosion from damp ashes, and no lime-mortar should be used, but only fire-clay. The width of the seating blocks in contact with the boiler-plates, even if flat, need not exceed 2 inches on the face, and for flue-covers $1\frac{1}{2}$ inches. As regards dampers, an automatic one worked by steam, and arranged to damp the fire automatically at any desired pressure, is to be preferred to a slide damper worked by hand, as this latter is often neglected by the attendant with a consequent loss of fuel. As regards a boiler covering for the prevention of radiation, although they do not show up dampness, a good deal can be said in favour of readily removable fire-clay covers, as fire-clay is a capital non-conductor of heat. In the place of ordinary fire-bricks, however, angular coverings, similar to Fig. 3, should be used; these are provided with angular contact ribs, which rest on the boiler longitudinally, and provide an envelope or chamber of hot air between the covers and the plates. It is important that any covers used can be quickly removed for examination, and these are usually laid on a sheet of asbestos, or similar non-conducting material.

In lieu of fire-clay covers, a good non-conducting composition, such as slag-wool, asbestos, or felt made up in

Fig. 3.

movable sections, or blankets capable of ready removal for inspection, is preferred by many; in fact, any cover that cannot be quickly removed and replaced is objectionable.

It is important that the fire-clay used in setting is from a well-tested bed, and that the boiler is truly set and supported, or considerable strain on the seams may be set up, particularly in the case of long boilers. After the boiler is fixed, it should stand for a few days to allow the masonry to harden, and only a small fire should be kept up for the first day, and steam raised very slowly.

CHAPTER VIII.

STEAM SUPERHEATING.

The question of superheating steam has of late years attracted considerable attention amongst engineers, and the general concensus of opinion is, that if the apparatus be scientifically constructed and applied, it effects a considerable saving. It need hardly be said that the object of superheating is to get rid of the water contained in the saturated steam made by the boiler, and this is effected by adding heat to it in a separate apparatus called a superheater, which is, however, practically an extension of the steam space of the boiler, and being in direct communication with it the pressure in both is approximately the same. The chief economy from superheating undoubtedly arises from the reduction of the initial condensation of the steam in the cylinder; at the same time the circulation in and steaming of the boiler is often considerably improved.

When we bear in mind that the loss from condensation in the cylinder and steam pipes with ordinary saturated steam may be anything up to 50 per cent. of the total steam used, the importance of superheating, which largely reduces this loss, will be at once apparent.

Steam is usually superheated from 100° to 250° F., but it is found in practice that if a very high degree of superheat is attempted, increased difficulty of cylinder lubrication and other troubles are set up which largely nullify the advantages gained from the higher temperature of the steam.

When superheated, steam becomes practically a gas and can be transmitted through pipes with less loss from condensation than saturated steam, at the same time the dangers of 'water hammer' are got rid of.

The advantages of steam expansion in the cylinder are also increased by superheating as the volume of the steam is still further expanded by the heat, and the drier the steam is delivered at the cut-off the greater the work done per lb. of steam used.

There appears to be little doubt, however, to the author that a large share of the economy arising from superheating must be attributed to the much higher temperature to which the internal cylinder walls are raised.

In deciding the amount of superheat to be used it should be borne in mind that although very high superheat is of increased value theoretically, in practice it often gives a lot of trouble. The amount of superheat should be largely determined by the class of engine: 150° to 200° will usually carry absolutely dry steam into the cylinder, and with old or low-class engines 100° of superheat will generally effect a considerable economy, the advantages of superheating of course being greater with low pressure steam than high.

Position of Superheater.—It is often a very difficult matter to arrange satisfactorily the proper position in which to place a superheater owing to the large variation in the type of boilers, heat of waste gases, site, &c.

Speaking generally, non-controllable heaters should be placed at a point where the heat of the waste gases do not exceed, say, 1,000° F., and where they do not fluctuate much, and in no case should they be subject to the direct impact of fire.

In the case of Cornish and Lancashire boilers the best position is in the downtake at the back of the boiler, where the heater is subjected to the direct action of the hot gases from the fire flues previous to their passage along the external flues on their way to the chimney. Steam can be admitted from the boiler by a junction valve passed through the heater tubes and thence into the main steam pipe. The supply of hot gases to the superheater tubes can be readily regulated or deflected from them by means of dampers. The writer has seen superheaters for these boilers placed in the uptake beyond the external flue; in his opinion this position is a very bad one, as the gases at this point have lost a large proportion of their heat and are generally at too low a temperature to effectively carry out their work.

In the case of water-tube and marine-tube boilers superheating is not so general and perhaps not quite so necessary as in other types. For these boilers, independently fired and controlled heaters should be used, as should non-controllable heaters be placed at the back of these short boilers the gases are too hot, and if the heat is used after it has passed the smoke tubes it is usually too cold.

For superheating portable or semi-portable tubular boilers a coil of tubes is sometimes fitted into an enlarged smoke-box.

In whatever position the superheater is placed care must be taken that it is not allowed to interfere with the draught.

On Selecting a Superheater.—Superheaters vary largely in construction, and their design and application should in all cases be very carefully considered, so that their type and the situation in which they are fixed is the best possible for the boiler to which they are applied, or the results may not be satisfactory.

Superheaters may be roughly divided into three classes, viz.: those (1) fired in the boiler flue, (2) in the combustion chamber, and (3) those independently fired. In selecting a superheater, complicated forms or those that cannot be readily cleaned or renewed should be avoided. Another important feature is that all tubes which are usually subjected to the action of very hot gases should have ample freedom to expand or fracture may soon take place. In downtake superheaters the tubes are often mounted in a separate chamber, which is fitted with a balanced swivel damper enabling the hot gases to be shut off from the tubes till steam has been raised.

Independently fired superheaters are more readily controlled and managed than the flue types, as in this case they need not be heated till the boiler has a full head of steam, and the superheat temperature can be easily regulated. All superheaters that can be shut off from the boiler should be fitted with an efficient safety valve. One of the externally loaded dead-weight type can be recommended, and the heater should be tested at least once a year by hydraulic pressure, as owing to the high temperature of the gases impinging against the tubes and joints they are liable to become overheated and in this case may rapidly deteriorate and an accident occur. Flanged joints should be avoided as far as possible and the hot gases should never be allowed to impinge directly on them.

It is not within the province of these pages to deal at length with details of construction, as superheaters must necessarily vary largely according to the type of boiler, site, &c., and each case should be carefully judged on its merits. Speaking generally, the writer recommends that the sectional area of the pipes for the passage of the steam through the heater be greater than that of the steam supply pipe or 'wire' drawing may be set up, although he is aware that some designers purposely reduce or throttle the area of these pipes with the object of increasing the velocity of the steam through them, it being claimed that with the higher velocity the moisture in the saturated steam is more rapidly taken up.

Another point that should be borne in mind in designing or selecting a superheater is that its cross-sectional area is correct for the steam pressure, the diameter of the tubes being reduced in ratio as the pressure increases.

In recent practice the tubes are made of weldless steel: copper should not be used as it becomes unsafe at very high temperatures. The non-controllable type of heaters are usually made with small tubes and the controllable with large; the former cost less than the latter but are much less durable.

Wherever possible, arrangements should be made for reducing the temperature of all superheaters in case of their becoming overheated or when raising steam. This can be done either by means of a damper deflecting the hot gases into a by-pass waste flue or by flooding the heater with water, the evaporation of which causes a rapid lowering of temperature.

Dampers arranged to admit a flood of cold air to the tubes to reduce their temperature are sometimes employed, but this plan is a wasteful one.

Non-controllable or integral superheaters have the advantages of low first cost and economical working, being heated by the waste gases from the boiler itself, but are subjected to more or less rapid deterioration. On the other hand, independently fired or controllable heaters possess various advantages over the non-controllable, but cost more in the first instance and the cost of fuel for independent firing has to be deducted from the saving effected by their use; on the whole, however, the author generally prefers the latter type. All superheaters, like the rest of the boiler, should be carefully examined at intervals for pitting, corrosion, incrustation, and other defects.

High Superheating.—Although very high superheating is theoretically the most economical, mechanical difficulties of construction are set up by its use such as the softening and rapid wear of the cylinder wall and valves, leakage of valves, joints, and steam fittings, and the largely increased difficulties of lubrication.

When an engine is especially intended for high superheating, the design, materials, and workmanship should be of the highest order, especial attention being given to the cylinder and valve gearing. Steel valves are generally used instead of cast-iron, and metallic packing for the rods.

Corliss or Trip valves are found to work satisfactorily at a temperature of about 500° F., but the ordinary flat slide valve will fail much earlier.

As there is much greater expansion when using superheated steam, especial allowance should be made in the steam pipes and expansion bends, and metallic or asbestos packing should be used for the joints as india-rubber and the ordinary packing are rapidly destroyed. All steam pipes should be of increased thickness.

Lubrication.—Owing to the intense heat engendered in the engine cylinder and valves by superheated steam their efficient lubrication is a matter of great importance in securing effective working, and where very high superheating is practised it sometimes gives considerable trouble.

A pure mineral oil, of the very highest grade and flash point can be used, to which the writer recommends the addition of a small quantity of the finest flaked graphite, say about a teaspoonful to a pint of oil, as this is unaffected by heat and reduces friction by filling up the minute holes in the iron on which it produces a fine smooth surface, at the same time the lubricating matter is retained longer between the rubbing surface. (For specification of a high-class cylinder oil see page 100.) The lubrication should be forced.

Note that no lubricating oil can exist at 650° F.

Where superheating is introduced, a pyrometer should in all cases be used, and the plant should be placed under skilled supervision, as it requires careful management to secure the best results in the saving of fuel and water, and to prevent undue deterioration.

I append a table giving the average saving of steam arising from superheating as compiled by Sugden :—

Temperature of Steam	Average Steam Consumption in lb. per I.H.P. per hour	Average Reduction in Steam used.
Saturated	14 to 15	—
Superheated, 50 degrees . .	13 ,, 14	8 per cent.
,, 100 ,, . .	12 ,, 13	14 ,,
,, 150 ,, . .	11 ,, 12	21 ,,
,, 200 ,, . .	10 ,, 11	26 ,,
,, 250 ,, . .	9·5 to 10·5	30 ,,
,, 300 ,, . .	9 ,, 10	34 ,,

Professor Gutermuth, in a report on a week's test of a Wolfe 100-H.P. locomobile (March, 1908) fitted with an intermediate superheater, gives the results as 1·04 lbs. of coal and 8·66 lbs. of steam per B.H.P. per hour, and says that the test showed an almost constant quantity of heat used—5,040 B.Th.U. per I.H.P. per hour for differences of loads up to 60 per cent.

An axial governor in combination with a piston valve was used, and kept the engine under control with a minimum variation of speed.

CHAPTER IX.

ADVICE TO BOILER ATTENDANTS.

We have pleasure in printing the following advice to boiler attendants, by permission of the Manchester Steam Users' Association.

General Working.

Treat your boilers with care and attention. Accidents are thereby prevented, expenses reduced, and the labour of firing lessened.

Water Level.—Before lighting fires see that there is sufficient water in the boiler. Test the water gauges frequently, and keep the water-level steady.

Blow-off Cocks.—Before lighting fires be sure that the blow-off cocks are closed and not leaking. Occasionally feel if the blow-off waste pipes are hot. Blow off from bottom before starting the engine. Sediment has then settled in the elbow pipe. Blow off the scum before stopping the engines, but only when the water-level is at the correct height. At such times most of the scum has collected in the troughs.

Lighting Fires.—Sudden changes of temperature may produce fractures or start leakages. Therefore never raise steam hurriedly. The top and bottom of a boiler should grow warm together. If convenient, fill the boiler with warm water through the economiser. If the boiler water is cold, allow fully six hours for raising steam. If pressed for time, fill the boiler to the top of the water gauge, fire slowly, and keep the safety-valve open until steam blows off freely. After closing the safety-valve blow out the bottom cold water until the working level is reached. The pressure may now be raised more quickly.

Smoke Prevention.—Smoke and imperfect combustion are caused by an insufficient air supply or by premature cooling of the flames. Therefore, after coaling, when the fires are black, admit air either at the door or through the split bridge. It is less wasteful to admit too much air than too little. With smoky boilers, or when hard pressed, keep the fires thin and even. Fire steadily. Don't coal all furnaces at once. Coal each furnace on one side at a time.

Emptying Boilers.—Do not empty the boiler while steam is up.

Overhauling, Cleaning, and Inspection.—Clean the boiler monthly or oftener, remove the scale while soft ; if possible, while emptying the boiler. Sweep the soot off the boiler plates and clean the flues every three months, as well as on the occasion of the annual inspection. All leakages should be stopped, any cause of dampness in the setting should be removed, corrosion should be arrested. The fusible plugs should be cleaned on the fire side and water side once a month, and the fusible metal should be renewed once a year at the time of the annual inspection. All cocks should be kept oiled, and unless asbestos packed they should be overhauled once every month. These cocks, the feed-valves, steam stop-valves, and all safety-valves should be overhauled annually on the occasion of the inspector's visit.

Warnings.

Manholes.—Before opening the manholes ease the safety-valve so as to be quite sure that there is no pressure in the boiler. Before entering a boiler secure the steam valves and blow-off cocks.

Safety-valves and Low Water Alarms.—The most disastrous explosions have happened with boilers whose safety-valves had been jammed down or overloaded. Never overload or tamper with safety-valves or with low water alarms. Ease or test them regularly every day. Be sure that they are in working order. If they will not work properly, reduce the steam pressure and then report to the manager. In doubtful cases he should write to the Manchester Steam Users' Association.

Steam Stop-valves and Steam Pipes.—Numerous fatal accidents have happened to boiler attendants while opening valves or drain cocks of steam pipes which had accidentally become filled with water. This water should be drained off, but only when the pipe is shut off from the boiler. The cracking noises which are sometimes heard in steam pipes, generally when opening a steam stop-valve or a drain cock, are a sign that water is being shot about by the live steam. Retire at once, for the next blow may be an explosion. Steam pipes which slope downwards from the boiler stop-valve to the engine appear to be quite safe. Horizontal pipes, particularly if their ends are turned up, are dangerous. They should be fitted with steam traps, or at least with drain cocks, and should always be kept dry.

Collapsed Furnaces.—(1) If, during the ordinary working of a Lancashire or Cornish boiler, the water was seen in the glass less than half an hour ago, but has disappeared, due to the feed having stopped, then probably no harm has yet been done. If the water was not seen for a long time, or if a mistake was made when last looking at the gauge glass, or if the water has disappeared suddenly and unaccountably, then there is a possibility that the furnace tops have come down, or are coming down, due to overheating. In either case, cool the plates from both sides as quickly as possible. Open the furnace doors to admit cold air, but don't disturb the fires ; ease the safely-valves, so as to cause priming. The rising froth is not so dangerous as cold feed-water, and will help to cool and stiffen the overheated plates. Afterwards increase the feed till the water shows in the gauge glass.

Collapsed Furnaces.—(2) If there is much scale, oil, or refuse in the boiler, the furnace sides and not the tops usually bulge in, generally very slowly. In this case cool the plates from the fire side ; open the doors ; if possible, cover the fires with damp ashes.

When exposed to these dangers the boiler attendant may prefer to retire. He should certainly not expose himself unnecessarily in front of the furnaces, and should warn others of the danger.

General Warnings.

Don't overload the safety-valves or tamper with them.
Don't let the water-level sink out of sight.
Don't allow the gauge cocks to set fast.
Don't open the steam stop-valves hurriedly.
Don't empty the boiler while steam is up.
Don't use unknown scale solvents or compositions.

CHAPTER X.

ADDITIONAL RULES, ETC., RELATING TO ENGINES AND BOILERS.

British Thermal Unit, or heat unit, is the quantity of heat required to raise one pound of pure water from 32° to 33° Fahr.

Joule's Equivalent, or British Thermal Unit, is equivalent to 772 foot-pounds of work, and is called the mechanical equivalent of heat.

The Unit of Work is the work required to be done to raise one pound weight through one foot, and is known as the *foot-pound.*

A Horse-power is equal to 33,000 lbs. lifted to a height of one foot in one minute, or equivalent motion against resistance.

Piston-speed.—To find the mean piston-speed of an engine.

Rule.—Multiply twice the stroke in feet by the revolutions per minute.

Indicated Horse-power.—To find the indicated horse-power of an engine.

Rule.—Multiply the area of the piston in inches by the mean pressure per square inch, and by the piston-speed in feet per minute ; divide the product by 33,000, the quotient is the indicated horse-power. Or P = mean steam-pressure on piston in lbs. per square inch ; A = area of piston in square inches ; R = revolutions per minute ; and S = stroke in feet. Then

$$\text{Piston-speed} = 2\,\text{S}\,\text{R}. \quad \text{Indicated horse-power} = \frac{2\,\text{S}\,\text{R}\,\text{P}\,\text{A}}{33{,}000}.$$

Mechanical Efficiency.—The ratio of the useful work to the total work is called the mechanical efficiency. Let I. H. P. = indicated horse-power ; B. H. P. = brake horse-power.

$$\text{Mechanical efficiency} = \frac{\text{B. H. P.}}{\text{I. H. P.}}$$

Suppose 25 per cent. of the power is absorbed in engine friction, the mechanical efficiency is 75 per cent. The efficiency of engines varies from 70 to 95 per cent.

Lap of Valve required to cut off Steam at a given point of the Stroke.

Rule.—From the length of stroke in inches deduct the distance in inches moved by the piston when the steam is cut off ; divide the remainder by the stroke of the piston in inches, and extract the square root of the quotient ; next, multiply the result by half the stroke of the valve in inches, and deduct half the lead from the product ; the remainder will be the required lap in inches.

To find the internal Bursting Pressure of Cylindrical Steam Boilers.

Rule.—Multiply twice the thickness of the plate in inches by one of the following constant numbers, and divide the product by the diameter of the boiler-shell in inches, and the quotient will be the bursting pressure in lbs. per square inch.

26,000 constant number for single-riveted joint of wrought iron.

32,500 constant number for double-riveted joint of wrought iron.

40,500 constant number for single-riveted joint of steel.

50,625 constant number for double-riveted joint of steel.

To find the Collapsing Pressure of Wrought-iron Flues or Tubes in lbs. per square inch.

Rule.—Multiply the square of the thickness of the plate in 32nd parts of an inch by the constant number 800, and divide that product by the product of the length in feet, multiplied by the diameter of the tube in inches.

To calculate the Horse-power of Lancashire Boilers from Firegrate area (American rule).

Rule.—Multiply the area of the firegrate by 4, the product will give the H.P. of the boiler when supplying an engine using 30 lbs. of water, or requiring 4 lbs. of good steam coal per indicated horse-power per hour.

Rate of Combustion in Steam Boilers.—The rate of cumbustion in steam boilers depends largely on the quality of the coal and the carefulness of the stoking ; but the following may be taken as a fair average per square foot of firegrate per hour, under ordinary circumstances :—Portable engine boilers, 9 to 16 lbs.; vertical boilers, 10 to 30 lbs. ; Cornish boilers, 12 to 14 lbs. ; Lancashire boilers, 12 to 16 lbs. ; marine boilers (natural draught), 16 to 24 lbs. ; locomotive boilers, 40 to 65 lbs.

Consumption of Feed-water by Steam Boilers.—High-pressure or non-condensing engines, about 30 to 40 lbs. of water per indicated H.P. per hour ; condensing engines, 20 to 30 lbs. ; triple expansion engines, about 12 to 16 lbs. Condensing engines require for injection water about 5 gallons per N.H.P. per minute.

Rules for ascertaining Diameter of Pulleys and Speeds of Shafts.

1. The speed of the driver and the diameter and speed of the driven being given, to find the diameter of the driver.

Rule.—Multiply the diameter of the driven by its number of revolutions, and divide the product by the number of revolutions of the driver ; the quotient will be the diameter of the driver.

2. The speed of the driven and the diameter and speed of the driver being given, to find the diameter of the driven.

Rule.—Multiply the diameter of the driver by its number of revolutions, and divide the product by the number of revolutions of the driven; the quotient will be the diameter of the driven.

3. The diameters of the driver and driven and the revolutions of the driver being given, to find the revolutions of the driven.

Rule.—Multiply the diameter of the driver by its revolutions, and divide the product by the diameter of the driven ; the quotient will be the revolutions of the driven.

INDEX.

PRINTED BY
SPOTTISWOODE AND CO. LTD., COLCHESTER
LONDON AND ETON, ENGLAND