BRITISH TRANSPORT COMMISSION

HANDBOOK FOR RAILWAY STEAM LOCOMOTIVE ENGINEMEN

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FOREWORD

The object of this book is to help enginemen to become proficient in their duties. In particular, it will be beneficial to cleaners and firemen in their preparation for promotion.

It is written with the object of giving a general description of locomotives and the principles involved in their construction and operation within the compass of a book of reasonable size.

The book deals with the steam locomotive, but it is the intention to follow it in due course with a similar publication dealing with other forms of motive power.

It should be emphasised that no one can become a proficient railway locomotive engineman merely by reading books, however good they may be. The highest proficiency, however, can only be achieved by studying the subject from all angles and putting into practice the knowledge and precepts gained from text-books.

The increased cost of fuel, together with the importance of punctuality, makes it essential that you should strive by all the means in your power to achieve the fullest knowledge of your work, and close study of this publication is one way which will assist you to do this.

R. F. HARVEY
Chief Operating and
Motive Power Officer

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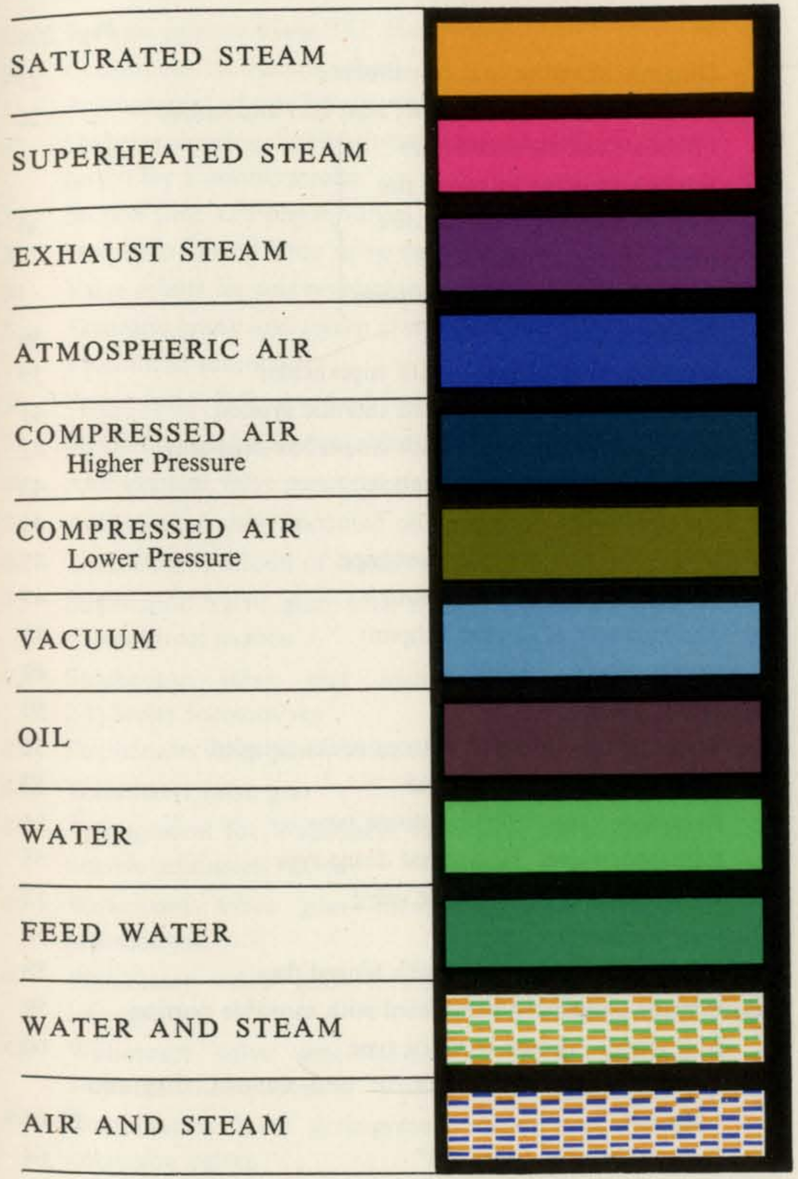

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SECTION 1

GENERAL

Introduction

The Junior Engine Cleaner who has started his career to become an Engineman on British Railways is expected to take an interest in locomotives, to fit himself to take charge of them when he is promoted. Whilst working as a Cleaner he must make himself acquainted with the general arrangement of the various types of locomotives and learn the names of the various locomotive parts, e.g. frames, cylinders, steam chests, wheel arrangements, boiler, firebox, smokebox, safety valves, etc. He will receive tuition from Chargeman Cleaners, Firing Instructors and Inspectors. He should take the opportunity to supplement the information in this Handbook by asking questions of Fitters, Drivers, Firemen, Foremen, Inspectors, and by attending Mutual Improvement Classes, and lectures in the Mobile Instruction Trains, where provided.

Notices and Rules

In addition to obtaining a knowledge of locomotives, it is essentia-
that he should become fully acquainted with the Rules and Regulal
tions which apply to him.

A study of the Permanent Notices and Rules 1 to 16 in the Rule Book will instruct him in his personal conduct and safety, and a knowledge of the following rules will prepare him for the time when he will be called upon to act as a Fireman :—

Rules Nos. 34-49	Fixed Signals
Rules Nos. 50-51	Hand Signals
Rules Nos. 55-56	Detention of Trains
Rules Nos. 126-8, 141-3	Working of Train
Rules Nos. 178-181	Protection of trains stopped by accident, etc.

He should have a knowledge of "Prevention of Accidents" as well as the proper procedure of coupling and uncoupling.

Cleaners

Before a Cleaner can be allowed to act as a Fireman he is required to show a satisfactory knowledge of the following subjects:—

(i) General description of a locomotive, i.e. names and uses of principal component parts.

(ii) General knowledge of Rules and Regulations particularly applicable to:—

Hand and fixed signalling.

Protection of trains and opposite or other lines.

Locomotive equipment.

(iii) Method of firing a locomotive, general duties and responsibilities of a fireman.

Examinations

A careful study of this Handbook will assist Firemen to become proficient in their duties and prepare them for their examination to pass as Drivers, which will be held on the following subjects:—

The technical examination to act as Driver, which will be carried out by a Motive Power Inspector, will comprise an oral and practical examination:—

(*a*) *Oral Examination*

The candidate to be examined in the following subjects:—

(i) Knowledge of locomotive.

(ii) Knowledge of mechanism of continuous brakes.

(iii) Method of dealing with locomotive defects.

(iv) Knowledge of rules and regulations.

(v) Knowledge of the various types of signals, their use and the rules relating to the reading of signals.

(vi) Knowledge of the making out of reports.

(*b*) *Practical Examinations*

The Examiner will give attention to the following points:—

(i) Care and manipulation of locomotive.

(ii) Attention to boiler and fire.

(iii) Attention to signals and judging distances.

(iv) Attention to rules and regulations.

(v) Knowledge of locomotive parts.

(vi) Making and using trimmings.

(vii) Care in and attention to oiling.

(viii) Examining locomotive and reporting defects.

(ix) General knowledge of automatic and steam brakes.

(x) Ability of examinee to change a boiler water gauge glass.

It must be clearly understood that the questions and answers printed in this book are not necessarily identical with those which will be asked at the examination.

ENGINEMEN'S DUTIES

Firemen

Good timekeeping is an essential part of a Railwayman's job. After signing on duty at the right time and reading the notices, the Fireman should then join his engine. His first duty is to examine the water gauges and notice the steam pressure. If the water level is satisfactory he should give attention to the fire, level it down and raise the steam pressure, to enable the injectors to be tested as early as possible.

He should satisfy himself that the fusible plugs and tubes are satisfactory and that the brick arch and firehole deflector plate and protection ring are in good condition, also the smokebox door is screwed up tight.

It is the Fireman's duty to draw tools and equipment from the Stores, where tools are locked up, and to clean and trim the lamps, where required to do so.

He must make sure that the required number of flags and detonators are carried and, where these are contained in a sealed canister, ensure that the seal is intact and the "date" indication correct.

Careful preparation of the fire is half the battle. He should start by spreading the fire over the grate evenly with a fire-iron, running this over the bars to clear the air spaces.

Some classes of coal require the use of broken firebrick, limestone or shingle, which prevents clinker adhering to the firebars. This must be thrown on the bars before spreading the fire.

The fire should be built up by adding small quantities of coal. Large coal must be broken to lumps little larger than a man's fist. This exposes to the action of the fire a greater surface of the fresh coal than would be the case if large pieces were used.

Firing should continue at intervals, giving each charge of coal time to ignite properly, until a bed of fire, well alight and suitable for the class of train to be worked, is obtained. The damper should be open and blower carefully applied sufficiently to avoid smoke.

He should be particular to sweep the front platform and the foot framing clear of all loose ashes and sand which would, if not removed, present an untidy and unkempt appearance, and, moreover, would blow into the motion and cause increased wear.

He should satisfy himself that the ashpan has been cleaned and that the dampers are in working order. The sand boxes must be filled, the fire-irons properly stowed and the coal safely stacked on the tender.

He should see that the cab, boiler fittings and tool boxes are kept clean; it must be remembered that a good Fireman takes a pride in the cleanliness of his footplate. When cleaning gauge glasses and protectors, he must make sure that the protectors are in good condition and that they are secured in the correct position. It is important that all pressure is released from the gauge glass before the protector is removed and that the protector is replaced before pressure is restored.

Any difficulties experienced or defects noted during preparation must immediately be brought to the notice of the Driver. The Driver is in charge of the locomotive and the Fireman's duties are carried out under the Driver's control and supervision.

Drivers

After signing on duty the Driver should read the current notices, sign for those which require it, and obtain his working instructions and any special instructions affecting his workings.

On arrival at the locomotive, the Driver should test the water gauges, satisfy himself that the fusible plugs and tubes are tight, note the condition of the fire and steam pressure, and see that the Fireman is correctly attending to his duties.

He should see both injectors tested and himself test the brake and sand gear, and, if any defects are observed, take steps immediately to have them remedied.

In making his examination and oiling of the locomotive, the Driver should have a definite system and always work to it. He should be acquainted with the differences in the layout of the various classes of engines with which he may have to deal in the course of his duties. By commencing at the same point, and always in the same order, he will deal with the various parts methodically.

The water pick-up gear, where fitted, should be tested and oiled and great care taken to see that the scoop is in the "UP" or "OUT" position and the handle secured to avoid any damage being done when the locomotive is moved.

When preparing a locomotive fitted with steam heating apparatus, during the carriage-warming season he should see that the flexible hosepipes and connections are in good order, the apparatus should then be tested by opening the cock at the tender end (or the cocks at each end on engines so fitted), next open the steam valve to discharge all condensation from the apparatus, close the cocks and see that the correct heating pressure can be obtained. If the regulation pressure cannot be obtained or is exceeded, the matter must be fully reported on a repair card and the defect remedied.

On engines fitted with rocking grates, drop grates or hopper ashpans the Driver should satisfy himself that the operating handle is in position, that the catches are secure and that the ashpan hopper doors are closed.

During the time an engine is being prepared, care must be taken to see that the safety precautions have been carried out and, before entering the motion, that the hand brake is hard on, the reversing gear in mid position and the drain cocks open in accordance with instructions contained in Permanent Notice B.R. 32709/1.

Working Trains

A Driver should have a thorough knowledge of the route over which the train is required to travel and have signed his Route Knowledge Card to this effect. If he is not fully conversant with any section he should obtain the services of a competent conductor.

The Driver must have with him on his engine a complete set of lamps, not less than 12 detonators and two red flags and such tools as may be prescribed by the Motive Power Superintendent. He is responsible for seeing that the prescribed lamps, etc., are exhibited and in good order and lighted when necessary. He must keep a good look-out when the engine is in motion, sound the engine whistle when necessary, especially as a warning to persons on the line and frequently when passing through tunnels, see that the proper signals are exhibited, observe and obey all signals, and all speed restrictions, have his Fireman disengaged when passing signalboxes, start his train carefully and proceed along the proper line, stop his train with care, paying particular attention to the state of the weather, the condition of the rails and the gradient as well as the length and weight of the train. During foggy weather he must keep a sharp look out for Fogsignalmen and when the signals cannot be seen assume that the signal is at caution or danger and proceed cautiously or stop immediately as the case may be. He must also observe the instructions contained in Rules 126 and 127 in addition to other instructions regarding the working of trains contained in the Book of Rules and Regulations, the General, Regional and Sectional Appendices and the Regulations for the working of the Vacuum Brake.

The Driver should always endeavour to operate the locomotive in the most efficient and economical manner consistent with the work to be performed by the use of the regulator and reversing gear.

His Fireman must, when not necessarily otherwise engaged, observe all signals and keep a good look-out all the time the engine is in motion. He must avoid waste of steam and water from injectors, strict attention being paid to the avoidance of unnecessary blowing off and creation of excessive smoke, and take care not to deposit engine ashes at other than the appointed places.

ENGINE DISPOSAL

Firemen

Towards the end of the run the fire must be levelled and worked down as low as possible to avoid arriving on the shed with a large amount of fire in the grate.

Upon arrival on the shed, and after reporting the arrival of the engine, coal will be taken and the tank filled with water, and the engine placed over the ashpit. After taking water the tank lid must be closed. Care must be taken during coaling to avoid spillage, and prevent damage to coaling apparatus by inadvertent movement of the engine.

On the ashpit the Fireman will, when required, empty the smokebox (locomotives fitted with self-cleaning smokeboxes will be dealt with in accordance with instructions). The fire will be withdrawn or cleaned as necessary and it is important to clear the ashpan thoroughly. Locomotives fitted with rocking grates and hopper ashpans will be dealt with in accordance with instructions posted at the Depot. Care must be taken to see that the hopper doors are left closed and secured and that the operating lever is replaced in position on the footplate.

It is essential to close the dampers and firehole door after the fire has been withdrawn, and the blower valve shut off to prevent the entry of cold air into the firebox, which would set up contraction stresses in the boiler plates, stays and tubes. (For the same reason the locomotive should, when necessary to move in own steam, be worked as lightly as possible to reduce the quantity of cold air which would be drawn through the empty firebox and tubes.)

The Fireman should collect, check and clean all tools and equipment for return to the stores or lock them up on locomotives where keys are provided. If any item has been lost or damaged he should inform the Driver, who will report the facts when signing off, and the Fireman should draw the Toolman's attention to the discrepancy when handing over the equipment.

Before leaving a locomotive after stabling, the boiler should be filled with water to a height of three-quarters of the gauge glass and the locomotive left secure with the hand brake hard on.

Drivers

Whilst the Fireman performs his disposal duties the Driver will make an examination of the locomotive; he should proceed systematically as when preparing and will book all known defects.

If necessary the Driver will make out a "Repair" card which should be written in ink or indelible pencil; it should be clearly filled in and as much detail as possible given concerning the defect. He should avoid reporting more than one item on one line of the card, each item to be clearly defined. He should be particular to report all blows and ascertain by test if necessary, during his examination, whence they originate.

He should note whether all valve spindles and piston rods and other points are properly lubricated, and examine all slide bar bolts, big and little ends, etc. Symptoms of defects noted whilst running should be properly reported. It must be borne in mind that the examining Fitter or the Fitter who will do the repair work may find the engine out of steam when he gets to it. The report should therefore convey to him as far as possible what is wrong so that he will be able to go straight to the defective part and not waste time examining parts that are working correctly.

If there are no known defects a "No Known Defects" card must be made out.

Before the locomotive is left, care must be taken to see that it is left secure with the regulator fully closed, reversing screw or lever in mid gear, cylinder cocks open, hand brake hard on and the blower valve closed.

Turning the Locomotive

An engine to be turned should always be taken on and off the turntable slowly and brought to rest easily to avoid straining the mechanism and the structure of the turntable. The competent Driver knows exactly where to stop, having previously noticed what part of that type of engine comes opposite a certain part of the turntable or to a landside mark as the case may be, so that he is able to stop quickly and easily in the desired position without waste of time re-setting. During the operation of turning, the hand brake must be screwed HARD ON, the reversing screw or lever in mid gear and the cylinder drain cocks opened.

Hand-operated turntables should always be pushed round and never pulled because, when pushing, the man operating the table is behind the bars so that if he should fall or slip the table will move away and leave him clear. A man pulling on the bar, however, might be injured if he slipped or fell because the bar would pass over him.

When operating a mechanically propelled turntable, in addition to the usual precautions taken to prevent movement of the engine, the propelling mechanism of the turntable must be handled carefully.

If of the vacuum tractor type, the starting valve must be opened slowly to minimise the shock to the gearing, care being taken to see that the catches are out before the tractor is started. The table must never be stopped by forcing the catches in. The tractor must never be used as a brake to stop the table by reversing. In all cases the tractor should be shut down at such a point that the table will roll to rest in the desired position of its own accord. The large ejector should always be used to create ample power to operate the tractor.

Enginemen called upon to work any kind of machinery must take certain elementary precautions in their own interest and that of others. They should take every opportunity to make themselves familiar with the different types of turntables and mechanised coaling plants and their controls.

A Fireman or a Passed Cleaner acting as a Fireman is under the control and supervision of the Driver upon whom falls the responsibility of assisting in training him in the early stages of his career. By tactful and careful instruction the driver, by recalling the time when he himself was in a similar position and acting on his own experiences, will have considerable influence which will reflect credit upon him, in addition to making each working day satisfying to both, in the knowledge of a job well done.

SECTION 2

COMBUSTION

Composition of Air and Coal

Combustion takes place when coal burns in air, and correct combustion can only be obtained by bringing together the right amounts of coal and air at the same time. To examine this statement more fully it is necessary that we should know something of the chemical constituents of coal and air.

Coal varies in quality and composition, but the greater part of it consists of carbon, the remainder being composed of gases and ash (see Fig. 1).

Air consists of a mixture by weight of approximately 23% oxygen and 77% nitrogen, or when measured by volume, 21% oxygen and 79% nitrogen.

Combustion is the chemical combination which takes place between the constituents of fuel and oxygen when the fuel burns. The heat-producing constituents of coal are carbon and hydrogen, heat being produced when these elements combine with the oxygen from the air. Coal must be heated to a temperature slightly above

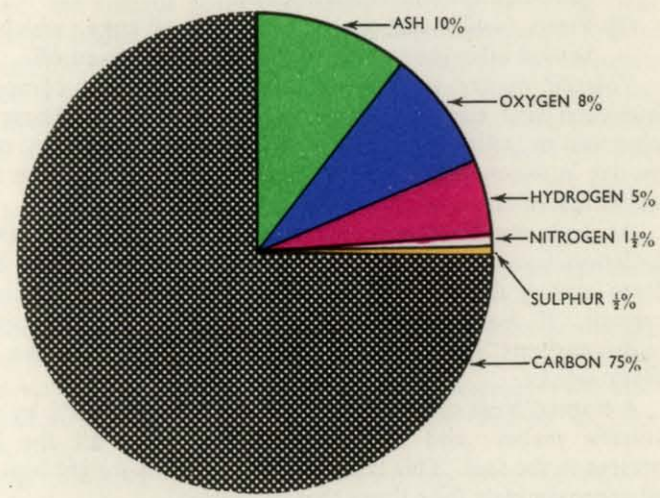


Fig. 1 AVERAGE COAL CONSTITUENTS

800°F. before it commences to burn, but very much higher temperatures are necessary for it to burn efficiently.

Carbon and hydrogen are chemical elements and each requires a definite quantity of oxygen to burn it completely so as to obtain the maximum heat value. In this connection it is necessary for the carbon to combine with sufficient oxygen to form a colourless gas known as carbon dioxide, and for the hydrogen to combine with oxygen to form water vapour (steam).

If, however, the supply of air is insufficient, incomplete combustion results and another colourless gas called carbon monoxide is formed. In burning to carbon monoxide only about 30% of the heat is produced as there is when adequate air to burn the carbon completely to carbon dioxide is supplied.

1 lb. of carbon completely burned to carbon dioxide produces 14,550 British Thermal Heat Units (B.Th.U.s).

1 lb. of carbon incompletely burned to carbon monoxide produces only 4,350 B.Th.U.s, that is, about 70% of the heat is wasted.

Now we have already given particulars of the constituents of coal, but it must be clearly understood that these elements do not exist separately in the fuel. The actual composition is extremely complicated, but it is sufficient if we consider it as consisting of two main parts:—

(1) Volatile (gaseous) matter, that portion which is given off as a gas when the coal is heated, and

(2) Fixed (solid) carbon, in the form of coke, which remains behind after the volatile matter has been given off.

Volatile matter consists of numerous gaseous compounds of hydrogen and carbon known as hydro-carbons. These may be observed as yellowish smoke issuing from the chimney of a locomotive in which steam is being raised from cold, or when too many shovelfuls of coal are put on at one firing.

At high temperatures, in the neighbourhood of 2,500°F., the hydro-carbons split up into carbon and hydrogen and are burned to form carbon dioxide and water vapour, provided sufficient air is present. If, however, there is a shortage of oxygen some of the hydro-carbons escape up the chimney unburnt in the form of black smoke.

A normal Yorkshire steam coal contains about 33% by weight of volatile matter, and this contains practically all the hydrogen present in the fuel. This latter has a weight-for-weight heating value of approximately four times that of carbon.

1 lb. of hydrogen completely burned to water vapour gives off 62,100 B.Th.U.s of heat.

The sulphur content of coal is small and is of little consequence as a heat-producer. It is, however, usually found in the coal as a compound of iron known as iron pyrites. The sulphur burns out, leaving the iron, which at high temperatures tends to cause the ash to become welded together forming clinker.

Nitrogen in the coal is of no consequence. The nitrogen in the air required for combustion, however, plays a very important part in actual practice. A considerable volume of nitrogen has to pass through the firebox in the air required for combustion; 1 lb. of coal requires approximately 12 lb. of air for combustion of which 9 lb. are nitrogen. The nitrogen does not burn, but it does restrict the rate of combustion. Also, due to the fact that it has to be heated up by combusted gases in the firebox, it causes considerable loss of heat. The loss is due to the high temperature at which the gases leave the chimney, approximately 700°-750°F., and the loss due to this is, at a minimum, 10%.

What Happens in the Firebox

Let us now consider what takes place when coal burns in a locomotive firebox. Air is supplied to the firebox in two ways, viz.:—

(1) Primary air, through the firegrate, and

(2) Secondary air supplied through the firehole.

Assuming coal has just been fired on to an incandescent (white hot) firebed, the volatile gases commence to be given off at once from the newly added coal, and are quickly drawn out of the firebox and through the smoke-tubes, and unless sufficient air for complete combustion is made available they will pass out of the chimney-top in the form of dense smoke. Whilst the volatiles mix with a certain amount of primary air this will almost invariably be insufficient, and they will therefore depend upon adequate secondary air supply through the firehole door to enable proper combustion to take place.

As has been stated previously, the volatiles contain a large proportion of the heat value of the coal, and any failure to provide adequate air for combustion of these will result in considerable heat loss. The fixed carbon, which remains after the volatiles have been driven off, remains on the firebed until sufficient primary air is provided through the firegrate to burn it, and here again sufficient secondary air must be provided to ensure that the carbon is fully burned to form carbon dioxide.

Heat loss can also occur through admitting more air than is required for combustion: this excess air does not take part in combustion, and is heated up by the burning gases in the firebox, losses occurring due to the high temperature of discharge from the

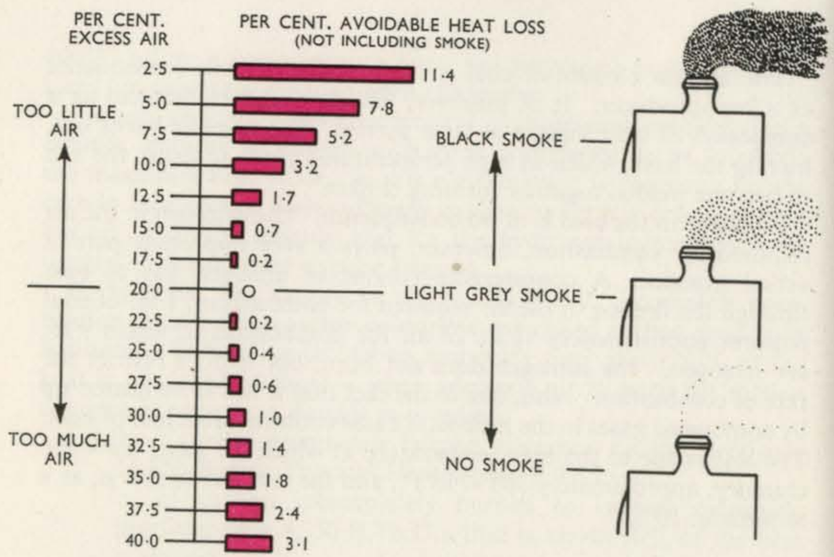


Fig. 2 EXCESS AIR, HEAT LOSS AND SMOKE

chimney in the same way as occurred with the nitrogen as described previously.

As a matter of interest, it is necessary to supply about 20% more air than is theoretically necessary to complete combustion in a locomotive firebox. If only the theoretically correct amount of air is supplied it is not possible to fully mix this with the combustible gases due to the high speed at which they are drawn through the firebox to the tubeplate, and losses occur due to incomplete combustion in consequence (see Fig. 2).

Principles of Good Firing

From the foregoing we have seen what conditions are required for efficient combustion; it is now necessary to see how proper combustion can be attained in actual practice.

On the road the art of firing is to regulate the fire and height of water in the boiler at all times according to the work to be performed and to have full boiler pressure when it is required, without blowing off.

Different types of coal require different handling, dependent upon their constituents. For example, a good-quality Welsh steam coal is very largely composed of fixed carbon and contains a comparatively small amount of volatile matter. Such coal requires a greater amount of primary air and less secondary air through the firehole

door. On the other hand, a good-quality Yorkshire steam coal is proportionately high in volatile matter and requires considerably more secondary air.

Coal will be economically burnt when the firebed is of the right thickness. If the fire is too thick the air cannot pass through it. If the fire is too thin, excessive air passes through the firebed and holes will be formed. In both cases the firebox temperature will be considerably reduced.

As already pointed out, the volatile matter begins to be expelled from the coal immediately it is placed on the firebed. If too much coal is fired at one time the amount of volatile matter given off will be so great that it will be impossible to provide enough air to burn it completely. The amount given off must therefore be controlled so that it is no greater than that which the air supply can burn completely. This can be done by firing only a relatively small number of shovelfuls at one time.

The whole of the volatile matter is not given off immediately the coal is fired and it is therefore necessary to wait before firing again FOR A PERIOD LONG ENOUGH TO ENSURE THAT THE AIR SUPPLY CAN THEN BURN THE VOLATILE GASES STILL BEING RELEASED FROM THE FIREBED TOGETHER WITH THE LARGER AMOUNT WHICH WILL BE GIVEN OFF IMMEDIATELY THE NEW FIRING TAKES PLACE.

Volatile matter requires an extremely high temperature for proper combustion, and one of the purposes of the brick arch is to maintain this high temperature. It increases the length of the path the gases must travel and causes them to be rapidly ignited. The brick arch receives heat from flames and radiation from the firebed itself and, therefore, the fire must be kept at the highest possible temperature. This can be done by working with a fire no thicker than the minimum needed to produce a uniform firebed without holes. To keep the firebed at this thickness the coal must be fired at the same rate as it is being burned away.

To obtain the maximum amount of heat for the production of steam, the best method of firing is to limit the amount of coal put into the firebox at one time and to fire again only when the last charge of coal has burned away.

Although steam locomotives appear to work harder up rising gradients they also travel more slowly and so use little (if any) more steam in a given period of time than when working more easily but travelling faster on easy gradients. This means that because the demand for steam remains fairly constant all the time the regulator is open, there is no need to increase the rate of firing to any great extent when climbing gradients.

Fire sparingly—work systematically. This is the essence of good firing and has been proved conclusively, not only by tests but by analysing the way the best firemen work in practice on the road. No hard and fast rules can be laid down because locomotives vary as much as the work they perform and the men who man them. However, for the larger locomotives the best results are found in practice to be achieved by not exceeding 12 shovelfuls at one time and by firing no more often than is necessary for good combustion. Smaller locomotives need proportionately less at a time, but the actual rate of firing will be found by simple observation, for when too many shovels of coal are being persistently thrown into the firebox black smoke will result and the thickness of the firebed will increase excessively.

For all classes of locomotives the most common mistake is over-firing, whether by large amounts haphazardly fired or by small amounts fired too often. Not only is valuable coal wasted as a result, but the job is also made harder than it need be, because combustion is less efficient.

Preparing the Fire

First make sure that the water level in the boiler is correct and that every part of the firebars is free from clinker and ash by running the fire-iron along them if necessary and knocking dust through into the ashpan. When the coal is of a clinker-forming nature, place two or three shovels of broken fire-brick or limestone on the grate; when ash is forming this will prevent clinker from running over the firebars, restricting the air passage.

Build up the fire in stages: put on a layer of coal and let this burn through; then add another layer, until the depth of the firebed is correct for the work in hand. This method ensures that the fire is properly burnt through before starting. If steam is not immediately required, regulate the dampers; this will prevent (1) the fire burning up too quickly, (2) making smoke, and (3) blowing off.

Make sure that the ashpan is clean, the smokebox door is screwed up tight and the fire-irons and coal on the tender are secure. When the locomotive is prepared prior to working a train, arrange the boiler water level so that the injector can be applied to prevent blowing off at the safety valves without overfilling the boiler.

It is very important, before starting away from the shed, to examine the fire; if there are any hollow places, fill these up, if possible with hand-picked coal. Make sure that there are no air-holes or dead patches in the firebed and that the fire is burnt through all over the grate. NO METHOD OF FIRING CAN BE EXPECTED TO PRODUCE SATISFACTORY RESULTS IF THE FIRE IS IN POOR CONDITION AT THE START.

Starting Away with the Train

On no account should the locomotive be fired when starting away. At this time the temperatures of the firebed and brick arch are much lower than they will be at any other stage of the journey. The object now is to raise their temperatures as quickly as possible. This can best be achieved by partly closing the firehole door; by this means the greater part of the air flow, called primary air, passes through the firebed and raises its temperature. The amount of volatiles being given off by the fire at this stage is small on account of the low temperature, and therefore a large quantity of air over the firebed, that is, through the firehole door, called secondary air, is not necessary if the fire has been prepared properly. If the coal is put on the fire before it has reached a high temperature, it merely cools the fire, delays good steaming and wastes coal (see Figs. 3, 4A and 4B). After the train has travelled a little way and the driver has notched up the gear, that is the time to fire. The first shovelful should be placed where the fire is thinnest and if it is being pulled into holes, these should be filled up smartly; if there are patches which are not burning properly, miss them. Watch the chimney; if the fire is correct there will be in 15-20 seconds a light smoke at the chimney-top. When this light smoke has disappeared it will be time to fire again; the fire should be burning evenly all over the grate and the appropriate number of shovelfuls, according to the type of locomotive and work to be performed, should be added.

Firing on the Journey

After a few firings the fireman will prove for himself that the rate of firing need be no more than "little and often" and this also applies when the engine is climbing gradients. It is, of course, quite true that engines burn more coal *per mile* on rising gradients than when running on the level, but this does not mean the fireman should fill the firebox with heavy charges of coal at one time. In such cases the number of shovelfuls fired should not exceed one or two, certainly no more than two, over the number used on the level. Good team work by enginemen has a bearing on maintaining a good head of steam; this co-operation between the Driver and Fireman is most important with regard to economy in the use of coal.

An inefficient Fireman sometimes blames the Driver for using steam at an excessive rate; on the other hand, the Driver may charge the Fireman with mismanagement of the fire, allowing the boiler pressure to fall, and in order to keep scheduled time it is necessary for the Driver to increase the engine cut-off, thereby using more steam. If, therefore, the Fireman provides a satisfactory boiler

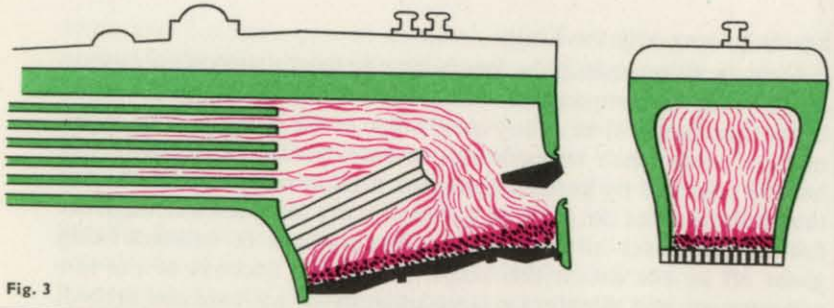


Fig. 3

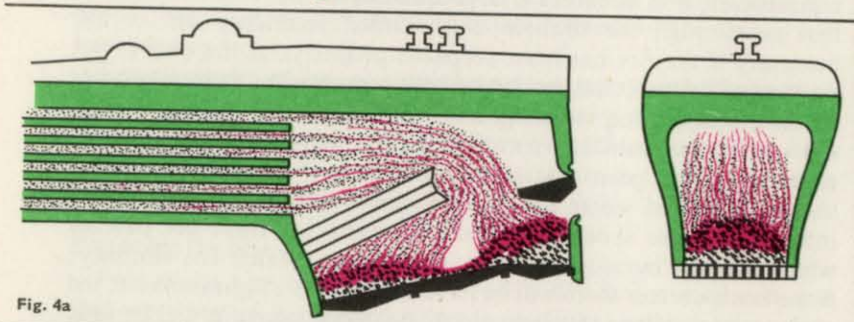


Fig. 4a

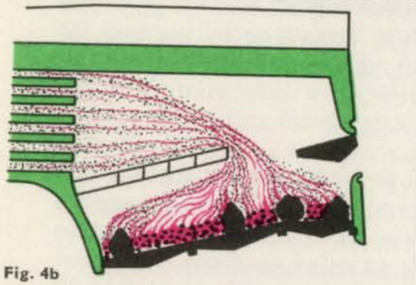


Fig. 4b

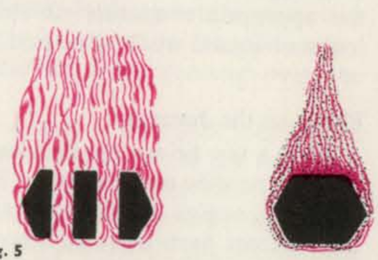


Fig. 5

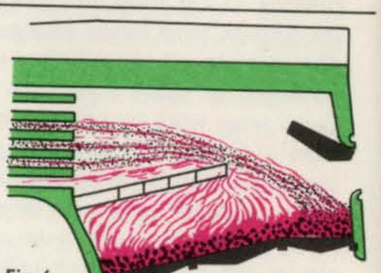


Fig. 6

Fig. 3 CORRECT FIRE
Firebed with even surface; no air holes, hollow places or dead patches; every square foot of grate doing its job; combustion space above firebed full of intensely hot flames; combustion completed in firebox

Fig. 4a INCORRECT FIRE
Firebed uneven; air unable to flow through thick patches under door and front of brick arch; too much air flowing through hollow patch and up to the sides of the firebox causing gaps in flames; combustion not completed in firebox; thick black smoke produced

Fig. 4b INCORRECT FIRES
Large lumps of coal cause dead spots in firebed, gaps in flame stream and uneven firebed surface

Fig. 5 EFFECT OF SIZE OF COAL
Many more surfaces are exposed when a piece of coal is broken; smaller pieces will cover a bigger area of the grate than a single large lump and help to produce enough flame to fill the combustion space fully. Large coal should be broken down to about the size of a man's fist.

Fig. 6 INCORRECT POSITION OF BAFFLE PLATE
Baffle plate tilted up allowing air to pass direct to upper part of tubeplate, setting up strains, chilling nose of brick arch and laying foundations for dirty tubeplate and leaking tubes

pressure, the Driver, by skilful handling of the gear, can carry out the work in hand without having to resort to the use of excessive rates of steam consumption.

When the Regulator is Closed

When the regulator is closed on the journey, or about to be closed, no firing should be done. Also, toward the end of a run, the rate of firing can be decreased or stopped completely at some point which is found by experience to avoid arriving on the shed with too great a quantity of fire in the box.

When locomotives are standing in stations or sidings waiting to leave at an unexpected time the fire can be kept right by placing a few shovels of coal very occasionally, first at one part of the grate and then at another. In this way excessive smoke is prevented and the fire temperature can be raised quickly when required.

Blowbacks

When an engine is steaming normally a rate of burning is maintained which is proportional to the rate of steaming. Coal is consumed on the grate, and the gases produced are burnt above the fire in the secondary air stream which is drawn through the firehole door by the action of the exhaust steam passing through the blast pipe. This air stream can also be maintained by the action of the blower and it draws the flames and also the products of combustion towards the smokebox. If this air stream is interrupted, e.g. by closing the regulator, without opening the blower sufficiently, the combustible gases which are still being produced will be trapped in the firebox with two possible results:—

(*a*) Combustion may continue in the vicinity of the firehole door where air is still available. In these circumstances combustion will move towards this area, and flames will issue from the firehole door, producing what is known as a non-explosive blowback.

(*b*) Combustion may cease momentarily, and the gases then re-ignited from the firebed; this would produce an explosive blowback with very rapid flame propagation and possibly more serious results, due to flames entering the cab.

Contributory factors to blowbacks are:—

(*a*) Hard coals and some briquettes with their distinctive long flames.

(*b*) Black fires which produce more combustible gases than can be consumed.

(*c*) Running bunker or tender leading with the damper immediately below the firehole fully opened. Combustion in these circumstances tends to be much more rapid in the vicinity of the air intake below the grate resulting in the emission of gases and the presence of flame in the vicinity of the open firehole door.

(*d*) Low tunnels and bridges may momentarily arrest the normal direction of the air-gas stream.

(*e*) A plate of the self-cleaning smokebox arrangement falling across the blast pipe due to insecure fixing.

The following points should, therefore, be borne in mind in order to avoid incidents of this nature:—

(1) Avoid black fires by overfiring, which besides wasting fuel produce excessive quantities of combustible gases.

(2) Always open the blower before closing the regulator, and also when approaching low tunnels, deep cuttings or bridges, especially when using hard coal or briquettes.

(3) Avoid using the trailing damper when running bunker or tender leading.

(4) During preparation ensure that the self-cleaning equipment in the smokebox is securely fixed.

(5) When locomotives are working coupled together, and it is necessary to take water when passing over water troughs, the footplate staff in charge of the locomotive in the rear must take the additional precaution of seeing that the blower is open and the damper and firehole doors are in the closed position.

Firing of Shunting Locomotives

The working of these locomotives is intermittent in character, so that the demands for steam are varied; nevertheless, the rules of efficient firing still hold good. The general principle of "little and often" can best be applied by adding a few shovelfuls of coal at each time and firing as far as is practicably possible only whilst the engine is working.

Size of Coal

A large lump of coal, which when thrown on to the firebed protrudes above the general level, will burn more slowly than the rest of the bed and create a dead spot in the fire. Since maximum efficiency can only be achieved with an even firebed, such lumps should be broken up so that they will burn at the same rate as the rest of the bed (see Fig. 5). A good size to aim at is about that of a man's fist.

Use of Fire-irons

Firemen should avoid the use of fire-irons as far as possible. If the fire is caked, the fire-irons should only be used to break up the surface. If there is a good depth of fire when the ash and clinker are lifted up and mixed with the incandescent fuel, the ash will melt and run into the spaces between the firebars making things worse. If clinker has formed and it is necessary to break it up whilst running, the fire should be run down as low as possible and the clinker will then be much easier to break.

Use of Baffle Plate

The baffle plate placed in the firehole is designed to direct the air down towards the firebed in order to mix it thoroughly with the hot gases and flames.

If this plate is not in place, tilted upwards or burnt too short, cold air can pass over the nose of the brick arch to the upper section of the tubeplate, setting up considerable strains in these parts of the firebox, causing leaking tubes, dirty tubeplates and giving poor combustion (see Fig. 6).

Use of Dampers

The dampers control the flow of air through the ashpan to the firebed and they can be used to good effect to control the rate of burning under all conditions when the regulator is closed.

There can be no hard and fast rule as to which dampers should be used when the regulator is open on the journey; this depends upon the judgment of the Fireman.

Working of Injector

Both injectors should be tried before leaving the shed with the boiler pressure close to its maximum to ensure that they are in good working order, so saving anxiety on the run. When starting away with a train the water level in the boiler should be in sight at the top of the gauge glass. The injector can then be left off until the Fireman has fired a few times and the firebed and brick arch temperatures have been raised. When the water level drops to about $\frac{1}{2}$ in. from the top, the injector can be put on; the steam valve should be well open and the feed-water regulator pulled round towards the minimum, in order to ensure that the water enters the boiler at the highest possible temperature. The Fireman will then be doing all he can to keep up a constant feed to the boiler. The quantity of water put into the boiler should be equivalent to the amount of steam used by the engine. The injector feed should be adjusted to obtain these conditions.

SECTION 3

TRANSFORMATION OF HEAT INTO POWER

The steam locomotive is a power plant in which there are four distinct divisions:—

(1) Fuel and combustion.
(2) Steam.
(3) Utilisation of steam.
(4) The driving mechanism.

Heat is a form of energy; therefore, when coal burns in the firebox of a locomotive its heat energy is capable of being expressed in terms of useful work. The high temperatures attained in the firebox by the combustion of the fuel varies according to conditions and may reach a maximum of 3,000°F. The heat so generated is transferred to the water in the boiler through the firebox plates and tubes, where it is converted to pressure energy in the form of steam, the steam in turn being led to the cylinders where it is transformed into mechanical energy and through the medium of the driving mechanism results in the tractive power of the locomotive.

British Thermal Unit

The production and utilisation of heat are the Fireman's chief concern; water and steam are only a means to an end—they bear the same relationship to a locomotive as does the harness to a horse that pulls the load. The state of the amount of heat or "hotness" in the firebox is measured by its temperature, and the unit of heat, in this country known as the British Thermal Unit (B.Th.U.), is 1/180th part of the heat required to raise the temperature of 1 lb. of water from freezing point to boiling point, i.e. 32° to 212°F., this being usually taken as the heat required to raise 1 lb. of water 1°F.

Methods of Heat Transfer

There are three methods by which heat may be conveyed from one body or place to another:—

Conduction:

Heat passes from one body to another by contact, warmer particles impart heat to the colder bodies. For example, boiler tubes transmit heat from the hot gases to the water through the metal by conduction.

Convection:

This is the transfer of heat by the hot gases in the firebox and by the circulating currents set up in the water, which takes the heat from the high-temperature parts. The moving hot gases in the firebox and circulating water in the boiler carry heat by convection to or from the metal surfaces with which they come in contact.

Radiation:

The fire in the firebox gives off energy in the form of radiant heat. Heat thus radiated to a body may be reflected, absorbed or transmitted. In the case of the firebox crown sheet the heat is absorbed by the metal, little being reflected, and the heat is then transmitted by conduction through the metal to the water.

Relation of Temperature to Pressures

When heat is applied to water to raise it to boiling temperature (212°F.), any additional heat will result in the water being transformed into steam at atmospheric pressure (14·7 lb. per sq. in.). Steam generated in a boiler, being enclosed, cannot escape, and if the application of heat is continued, more and more water is converted into steam which, being elastic, becomes compressed, decreases in volume and increases in pressure. As the pressure of steam on the surface of the water increases, so the temperature at which the water turns into steam rises correspondingly.

At atmospheric pressure (0 lb. per sq. in. on pressure gauge) 1 cu. in. of water when converted into steam occupies 1,642 cu. in. or nearly 1 cu. ft. At 15 lb. per sq. in. on the pressure gauge this steam will occupy only 821 cu. in., the pressure being doubled and the volume reduced by half. At 30 lb. per sq. in. the volume is only 410 cu. in., the steam being now compressed to one-fourth of its original volume. At 250 lb. per sq. in. the volume of 1 cu. in. of water converted into steam is only 110 cu. in.

Saturated Steam

The steam collected above the water in the boiler, termed "saturated steam", exerts an increasing pressure on its surface which resists the formation of the rising steam bubbles and calls for additional heat energy in the water. In short, the higher the pressure the greater the amount of heat required to create steam; for example:—

Steam at atmospheric pressure has a temperature of 212°F.
Steam at 85 lb. gauge pressure has a temperature of 327°F.
Steam at 225 lb. gauge pressure has a temperature of 397°F.
Steam at 250 lb. gauge pressure has a temperature of 405°F.

A table showing the range of steam pressure and temperature is given below:—

STEAM PRESSURE-TEMPERATURE TABLE

Gauge Pressure lb. per sq. in.	Temperature °F.	Gauge Pressure lb. per sq. in.	Temperature °F.
0	212·0	170	375·2
50	297·9	175	377·4
100	337·8	180	379·6
120	350·0	185	381·7
130	355·5	190	383·8
140	360·8	195	385·9
150	365·8	200	387·9
160	370·6	220	395·6
165	372·9	250	406·3

Superheating

Should the steam be further heated while in contact with the water from which it was generated, more water will be evaporated and the quantity of steam increased with an increase of temperature and pressure until the action of the safety valves prevents any further increase. On the other hand, if heat be added to the steam apart from the water from which it was generated, the steam becomes *superheated* and its temperature rises above that due to its pressure. The superheating of the steam is generally performed while the steam is no its passage from the regulator valve to the steam chest.

The temperature of superheated steam at working pressure ranges from about 600°F. to 750°F. depending upon the design of the superheater and the way in which the locomotive is being worked; in other words, the steam is heated about 300°F. above the saturated steam. The three main advantages of superheating the steam are that any entrained water in the saturated steam is converted into additional steam, cylinder condensation is prevented and the volume is increased as compared with saturated steam. This increase in volume is approximately 30% at a working pressure of 225 lb. per sq. in.; in consequence of this increase the demand upon the boiler to supply steam to the locomotive cylinders is considerably reduced, resulting in a saving in water and fuel.

The arrangements of the superheater and the utilisation of the expansive properties of the steam are described in subsequent sections.

SECTION 4

THE BOILER:
BOILER MOUNTINGS AND DETAILS

Types of Boilers and Fireboxes

The boiler or steam generator consists essentially of the steel shell, which includes the boiler barrel, the outer firebox wrapper plate, back plate, throat plate and smokebox tubeplate, also the inner firebox and the steel flue tubes. Fig. 7 shows a design of a boiler supplying saturated steam and Fig. 8 a boiler for supplying superheated steam. The latter figure illustrates a taper boiler, the cylindrical barrel is made in two sections with the larger diameter at the rear, where the barrel is joined to the outer firebox. The dome in this design, which houses the regulator valve and auxiliary internal steam pipes, is positioned on top of the rear sloping section of the boiler barrel, where it forms a collector for steam above the surface of the water.

Fireboxes may be of the deep, long, narrow type between the frames or of the shallow, wide type, for example, as fitted to 4-6-2 classes of locomotives. In the latter case the firebox is spread over the frames. The wider type of firebox is generally employed when a large grate area is necessary.

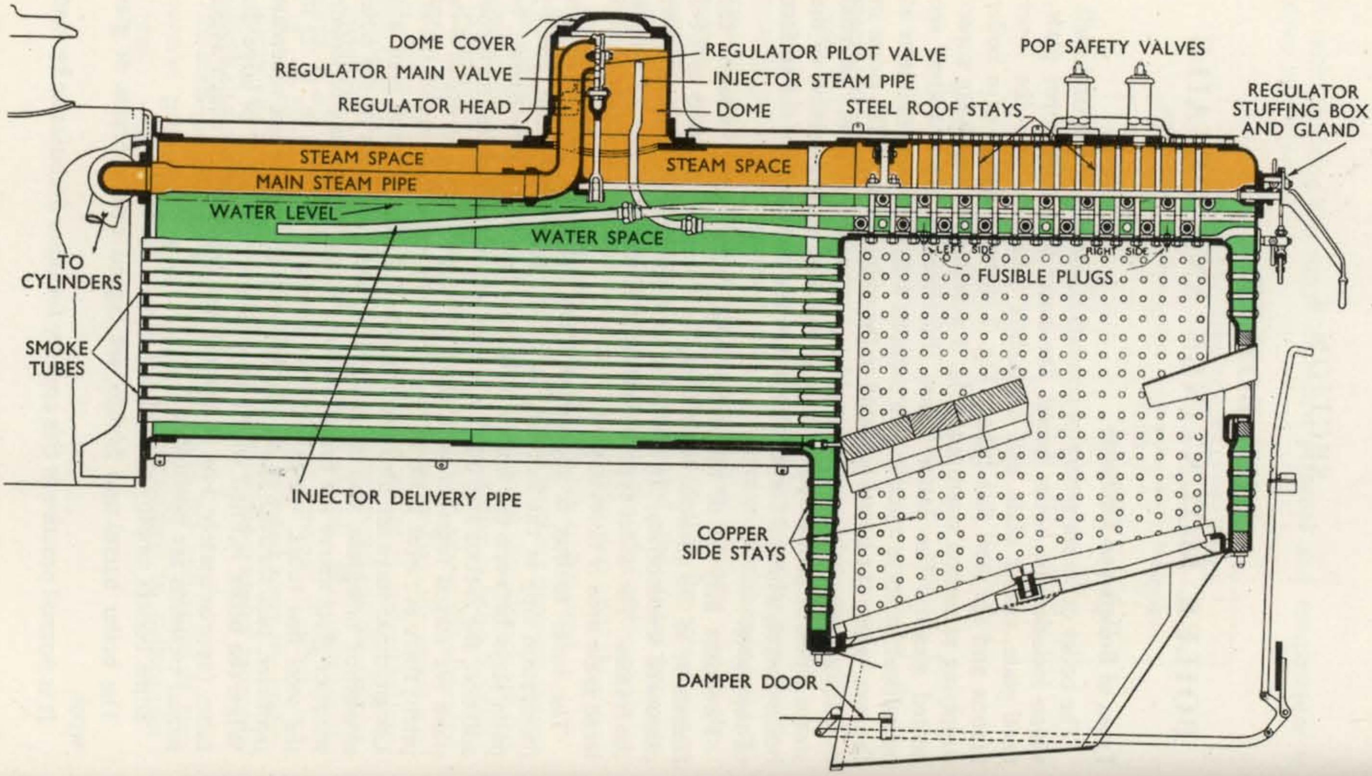
The inner firebox is supported from the outer firebox by the foundation ring at the bottom, by crown stays at the top, and by palm stays between the firebox tubeplate and the boiler barrel. In addition, the firebox and outer wrapper plates, back plate and throat plate are stayed together with steel or copper stays, at about 4-in. pitch; there are over 1,000 of these stays in every locomotive boiler. Longitudinal stays are also fitted between the boiler back plate and smokebox tubeplate, and cross stays between the sides of the outer wrapper plate above the firebox crown. From the firebox tubeplate, the steel flue tubes, which may be anything from 1½ in. to 2¼ in. diameter, pass through the boiler barrel to the smokebox tubeplate. When the boiler is fitted with a superheater, a number of large flue tubes (approximately 5 in. diameter) are provided in which superheater elements are positioned.

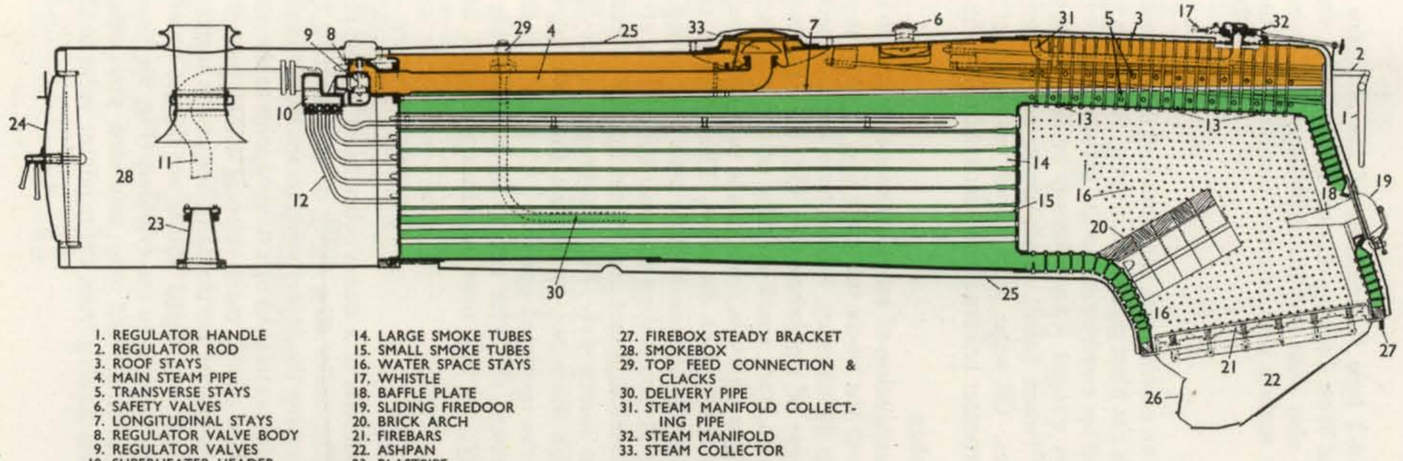
Some boilers employ the flat-top type of firebox.

The boiler barrel and firebox are lagged with asbestos or glass wool.

It is normal practice in this country for inner fireboxes to be made

Fig. 7 SECTIONAL VIEW OF BOILER





1. REGULATOR HANDLE
2. REGULATOR ROD
3. ROOF STAYS
4. MAIN STEAM PIPE
5. TRANSVERSE STAYS
6. SAFETY VALVES
7. LONGITUDINAL STAYS
8. REGULATOR VALVE BODY
9. REGULATOR VALVES
10. SUPERHEATER HEADER
11. STEAM PIPE TO CYLINDERS
12. SUPERHEATER ELEMENTS
13. FUSIBLE PLUGS
14. LARGE SMOKE TUBES
15. SMALL SMOKE TUBES
16. WATER SPACE STAYS
17. WHISTLE
18. BAFFLE PLATE
19. SLIDING FIREDOOR
20. BRICK ARCH
21. FIREBARS
22. ASHPAN
23. BLASTPIPE
24. SMOKEBOX DOOR
25. BOILER CASING
26. FRONT DAMPER DOOR
27. FIREBOX STEADY BRACKET
28. SMOKEBOX
29. TOP FEED CONNECTION & CLACKS
30. DELIVERY PIPE
31. STEAM MANIFOLD COLLECTING PIPE
32. STEAM MANIFOLD
33. STEAM COLLECTOR

NOTE:—*THIS TYPE OF ENGINE IS FITTED WITH A MULTI VALVE REGULATOR*

Fig. 8 SECTIONAL VIEW OF BOILER WITH SUPERHEATER of copper. The 4-6-2 type locomotives of the Southern Region (Merchant Navy and West Country classes) are, however, fitted with steel fireboxes and also with thermic syphons which increase the firebox evaporative surface and improve circulation in the boiler (see Fig. 9).

The Smokebox

The smokebox is an extension at the front end of the boiler barrel which, together with the blast pipe and chimney, forms the means of inducing air required for combustion to the firebox. Apart from the chimney orifice it is airtight. Other fittings in the smokebox are: superheater header (when fitted), main steam pipes, blower and ejector exhaust pipes. On some locomotives the regulator valve is situated in the superheater header in the smokebox (see Fig. 10).

Self-cleaning Smokebox

To avoid the accumulation of ashes in the smokebox, to even the effect of the blast over the whole tubeplate and to prevent emission of sparks thrown up the chimney, locomotives are now being fitted with self-cleaning type of smokebox (see Fig. 11). Deflecting and diaphragm plates with front spark arrester or ash plate are fitted. The vertical diaphragm plates, in front of the tubeplate, ensure that an equal draught passes through the tubes. The self-cleaning action is attained by locating the horizontal table plate just under the top flange of the blast pipe and setting the restriction plate at such an angle as, combined with sufficient area of netting, will allow for the free steaming of the locomotive. The diaphragm plates cause the ashes, drawn through the tubes, to traverse the lower part of the smokebox through the restricted opening "A" (Fig. 11); the ashes are then drawn through the wire net screen before being ejected through the chimney. By that time the ashes are small, dead and harmless.

The Superheater

The superheater consists of a steam collector or header for distributing steam from the boiler to a series of superheating tubes or elements and for receiving the superheated steam from the elements. The superheater header is attached by a flanged joint to the smokebox tubeplate at the outlet of the main internal steam pipe from the regulator valve and is placed horizontally across the upper part of the smokebox. At each side of the header are flanges to which are attached the main steam pipes to the cylinders (Fig. 9).

The header casting is divided into saturated and superheated compartments. Steam passing from the regulator valve to the main

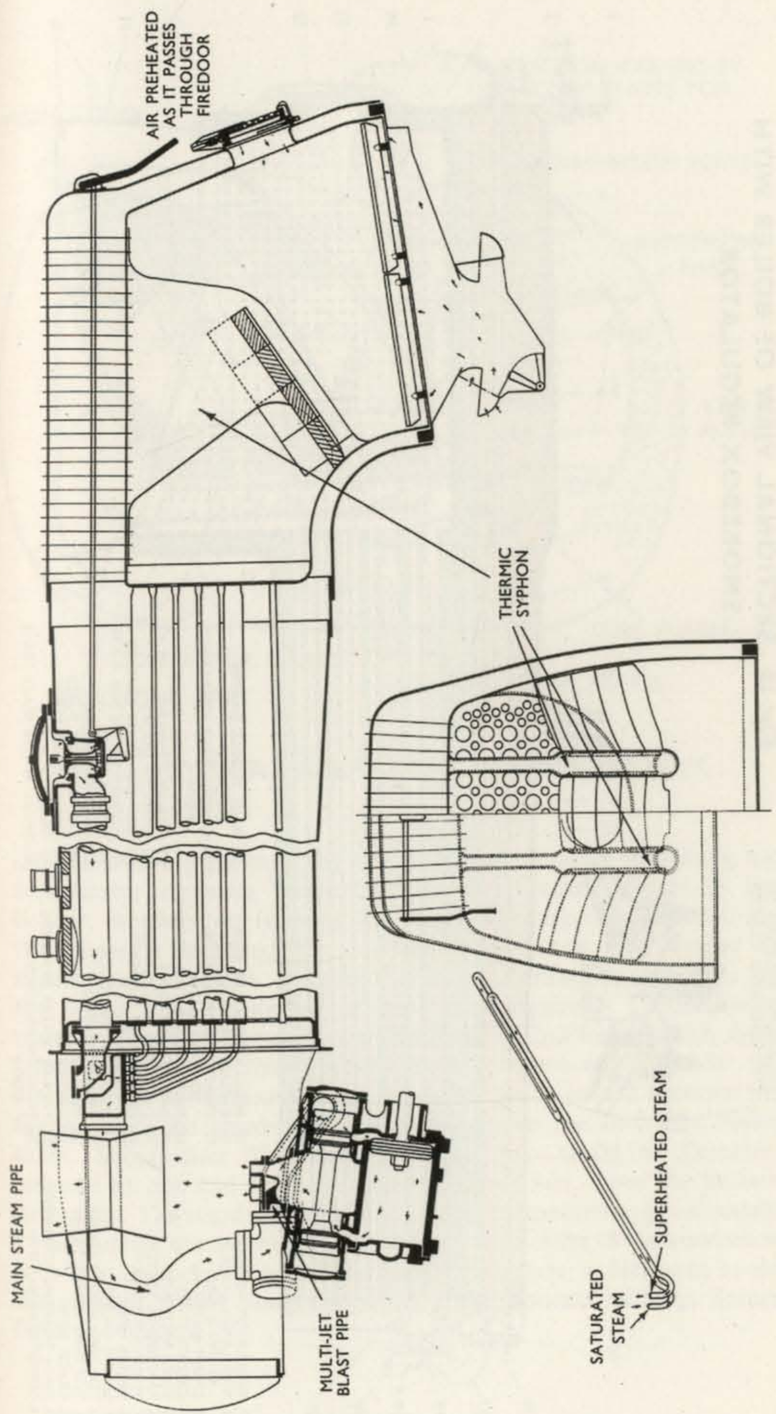
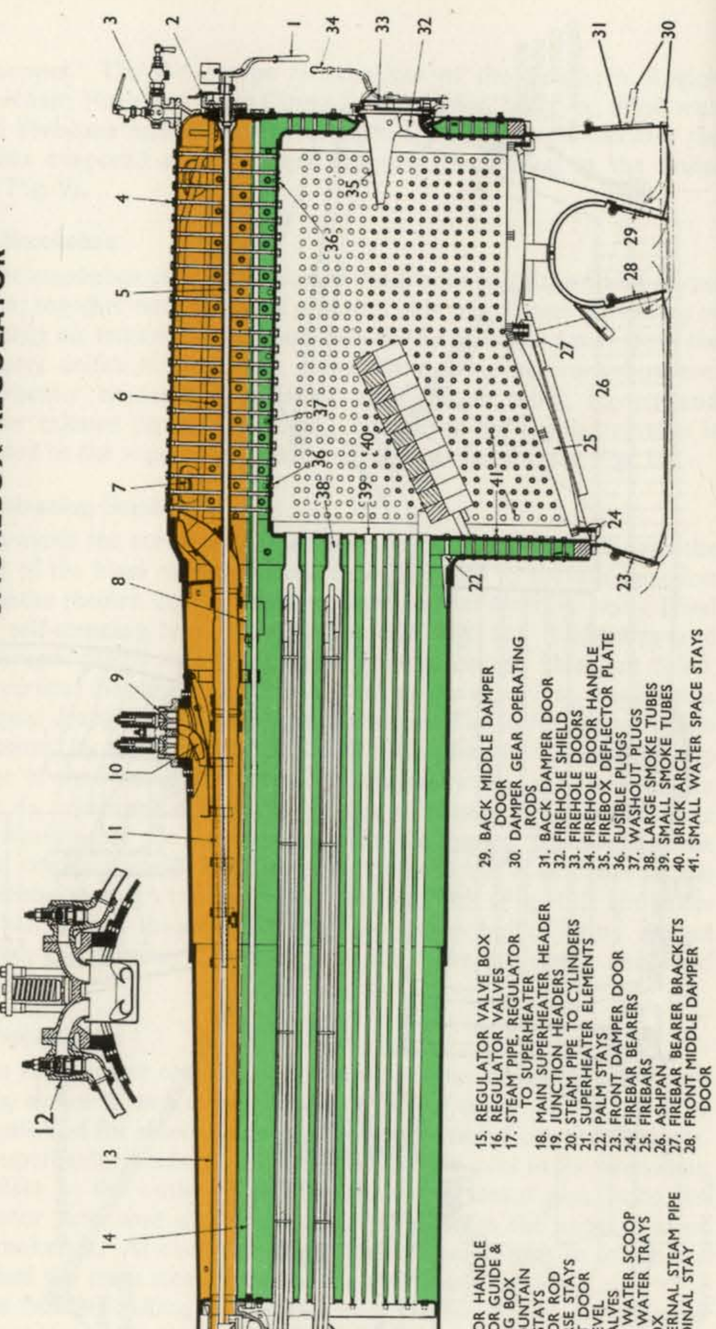


Fig. 9 SECTIONAL VIEW OF BOILER WITH THERMIC SYPHON

Fig. 10 SECTIONAL VIEW OF BOILER WITH SMOKEBOX REGULATOR



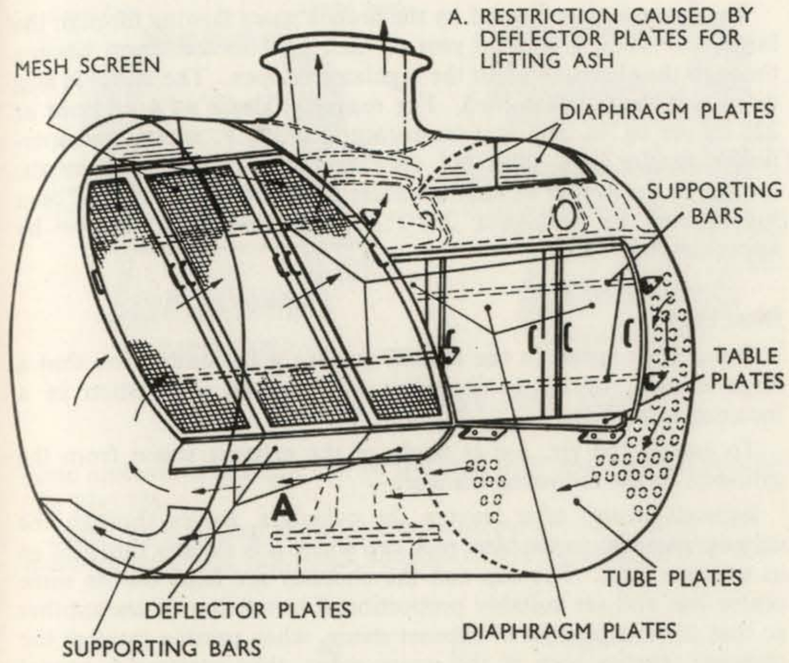


Fig. 11 TYPICAL SELF-CLEANING SMOKEBOX

internal steam pipe can only reach the cylinders by traversing the superheater elements connecting the two compartments in the header, the elements forming the only communication between the two separate sections. On modern locomotives the number of superheater elements installed varies according to the size of the boiler and the degree of superheat required. The elements usually consist of continuous steel tubing of four lengths with three return bends, or of the bifurcated type with two return bends: the elements are positioned in large flue tubes which extend between the firebox and the smokebox tubeplates above the ordinary boiler tubes. Superheater flue tubes are from 5 in. to $5\frac{1}{2}$ in. diameter, reduced at one end for a distance of about 8 in. from the firebox tubeplate. The standard superheater element measures approximately $1\frac{3}{8}$ in. outside diameter and extends from the header in the smokebox to within a short distance of the firebox tubeplate, sufficient to avoid the element return bends coming in direct contact with the flames from the firebox.

The steam is superheated by the firebox gases flowing through the large flue tubes, giving up part of their heat to the steam passing through the elements when the regulator is open. The steam is first dried and then superheated. For example, steam at a pressure of 225 lb. per sq. in. and at a temperature of 397°F. enters the superheater header in a saturated state and, traversing the elements, returns to the header at a temperature of about 600°F., having been superheated by just over 200°F. and increased in volume by approximately 35%.

Blast Pipe

It has been stated in the section dealing with combustion that a large amount of air is necessary for efficient combustion in a locomotive firebox.

To supply the air, use is made of the exhaust steam from the cylinders in the following manner:—

Exhaust steam, after leaving the cylinders, passes through the exhaust passages to the blast pipe cap where it is slightly throttled so as to form a jet. The cap and the chimney are fixed on the same centre line and are suitably proportioned in relation to one another so that the escaping jet of exhaust steam, when passing through the chimney, carries with it the waste gases, thus creating a partial vacuum in the smokebox which induces the firebox gases to pass through the flue tubes and which, in turn, induces air to pass into the firebox through the grate and firehole door.

If the smokebox door is not airtight the vacuum will be reduced and bad steaming will result.

Whilst the majority of locomotives have a blast pipe cap of the fixed cone type, as described above, there are several variations. On ex-G.W.R. locomotives fitted with superheaters the "jumper"-type blast pipe cap is in extensive use.

It consists of a blast pipe cap fitted with a "jumper" ring and when the locomotive is working heavily the exhaust steam pressure lifts the jumper ring and provides an additional outlet for the exhaust, thereby reducing the tendency to lift the fire (see Fig. 12).

For this type of cap to fulfil its purpose it is most important that it should be kept clean and in good working order and the Fireman should brush away any accumulation around the top each day when he examines the smokebox. If the top is found defective it must be reported.

The double blast pipe cap comprises two fixed cone exhaust caps and requires two chimneys. The advantage of this design is that the

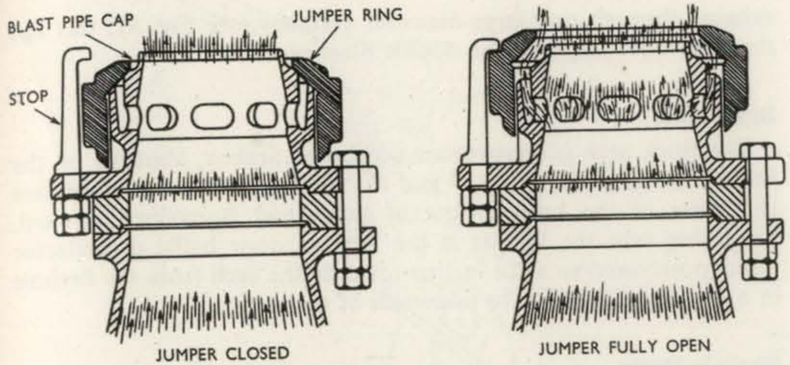


Fig. 12 JUMPER BLAST PIPE TOP

same amount of draught can be induced with less exhaust pressure (see Fig. 13).

Many ex-S.R. express passenger locomotives are fitted with a multi-jet blast pipe cap which consists of five exhaust nozzles which

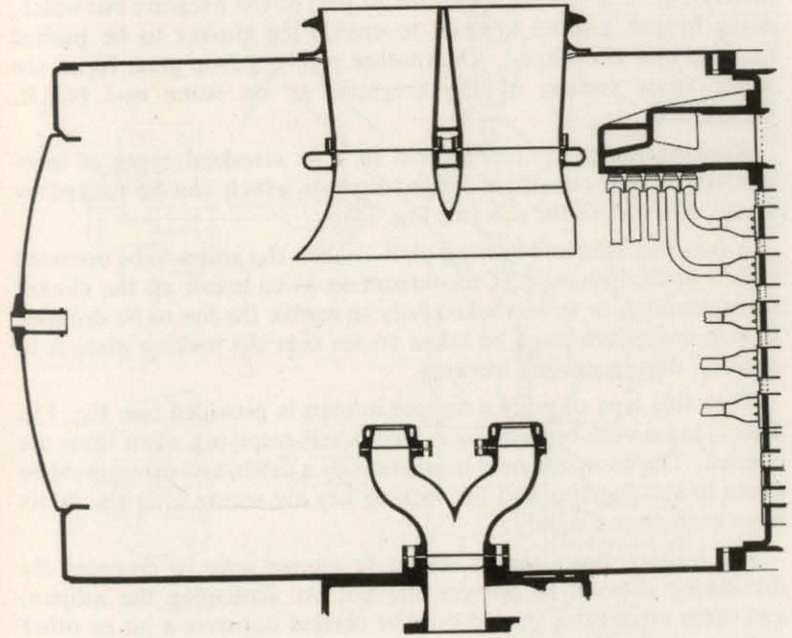


Fig. 13 ARRANGEMENT OF DOUBLE BLAST PIPE

exhaust through one large-diameter chimney (see Fig. 9); this has the same advantages as the double blast pipe.

Brick Arch

The brick arch is constructed within the firebox, abutting on the firebox on each side (Figs. 7 and 8). It extends from the tubeplate just clear of the bottom row of tubes and is inclined upward. Projecting into the firebox is the firehole door baffle or deflector plate, positioned so as to incline towards the arch from the firehole in a line slightly below the underside of the arch.

Firehole Doors

Various patterns of firehole door are fitted to locomotives; these give access for firing and also can be adjusted to control the ingress of secondary air.

Drop Grates and Rocking Grates—Hopper Ashpan

Drop grates are fitted to facilitate disposal of the fire.

They are of varying types. One type consists of cast iron approximately 2 ft. × 1 ft 3 in., which forms part of the firegrate but which, being hinged, can be lowered to enable the clinker to be pushed through into the ashpan. On another type the drop grate forms the whole front section of the firegrate, as on some ex-L.N.E.R. locomotives.

Rocking grates are being fitted to B.R. standard types of locomotives. These consist of hinged firebars which can be rocked by means of levers in the cab (see Fig. 14).

A two-way stop and locking plate enables the grates to be operated with a limited amount of movement so as to break up the clinker when running, or to be rocked fully to enable the fire to be dropped at disposal. Care must be taken to see that the locking plate is in position during normal working.

With this type of grate a hopper ashpan is provided (see Fig. 15). This is fitted with bottom doors and is self-emptying when these are opened. The doors are held in position by a catch, and care should be taken to see that this and the locking key are secure after the doors have been closed tightly.

The hopper doors *should always be opened prior to dropping the fire during disposal* to prevent the hot fire damaging the ashpan, and these operations should only be carried out over a pit or other authorised cleaning point.

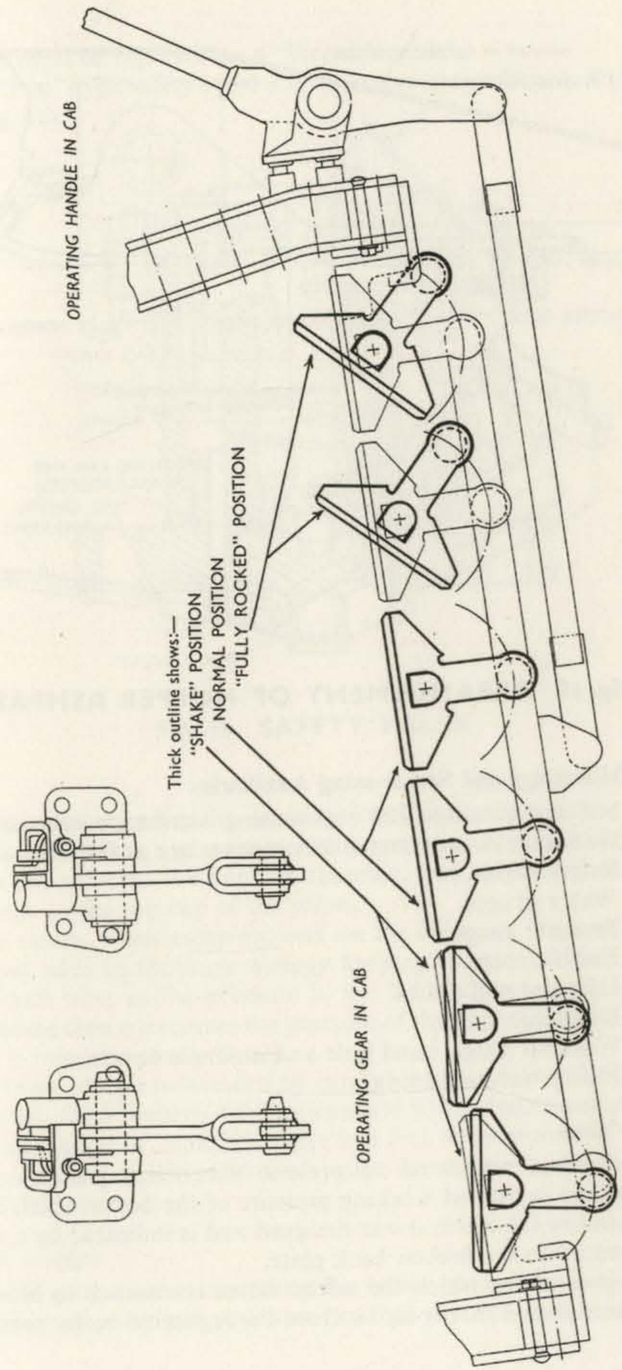


Fig. 14 ARRANGEMENT OF ROCKING GRATE

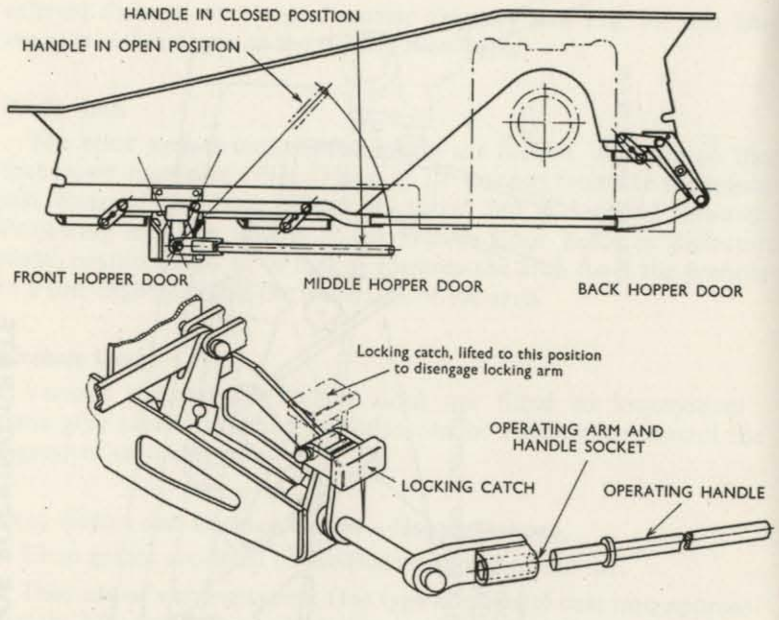


Fig. 15 ARRANGEMENT OF HOPPER ASHPAN

Boiler Mountings and Steam-using Auxiliaries

The boiler mountings and steam-using auxiliaries necessary for the efficient and safe working of locomotives are as follows:—

1. Safety valves.
2. Water gauges.
3. Pressure gauge.
4. Fusible plugs.
5. Injectors and clacks.
6. Regulator valve.
7. Washout plugs, hand hole and mudhole covers.
8. Blower valve and ring.

Safety Valves

Safety valves are fitted to prevent the boiler pressure from exceeding the registered working pressure of the boiler which is the steam pressure for which it was designed and is indicated by a metal tablet secured to the firebox back plate.

If the pressure at which the safety valves commence to blow off differs more than 5 lb. per sq. in. from the registered boiler pressure,

this fact must be reported on a "Repair" card.

The "Pop"-type safety valve is in extensive use on British Railways (see Fig. 16).

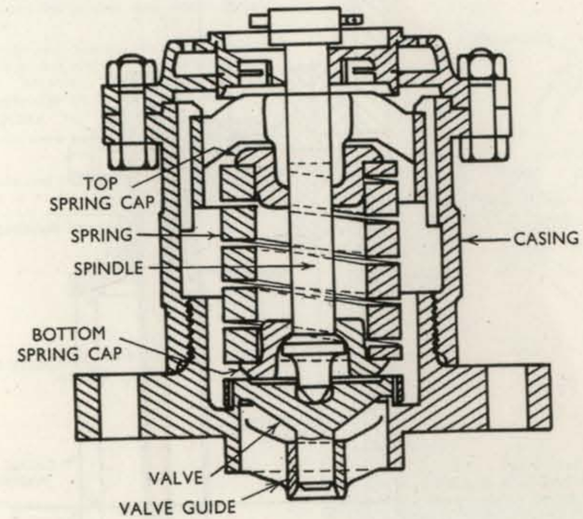


Fig. 16 SAFETY VALVE

In this design, when the working pressure is reached, the spring-loaded valve rises and admits small amounts of steam through a lip on the valve to the annular chamber, and this escapes through the holes in the top cap of the valve.

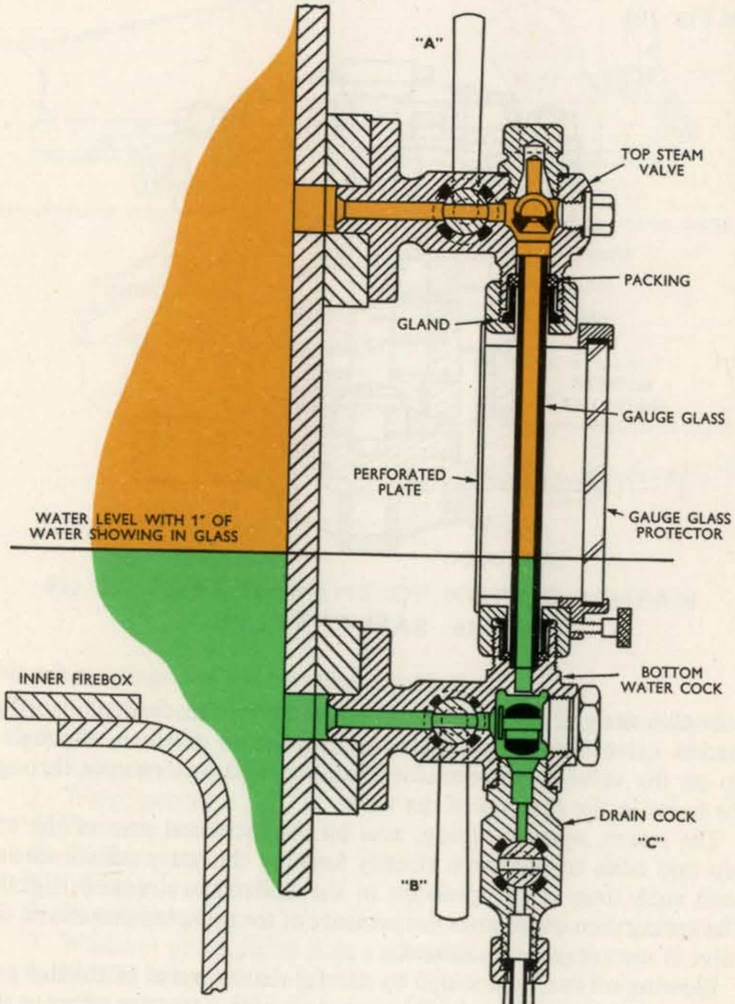
The steam, when escaping, acts on the increased area of the top cap and adds to the force already keeping the valve off its seating until such time as the pressure in the boiler has dropped slightly. The spring then overcomes the pressure of the escaping steam and the valve is instantaneously closed.

Blowing off can be avoided by careful management of the fire and injectors. On a modern 4-6-0 locomotive with a tractive effort in the neighbourhood of 26,000 lb. there is a loss of pressure and wastage of approximately 10 gallons of water for each minute the safety valves are open.

Water Gauges

Water gauges are mounted on the boiler back plate in the cab of the locomotive and are positioned so that when the water is in sight

Fig. 17 WATER GAUGE



TO TEST GAUGE COCKS

1. Shut top cock and bottom cock by pulling handles **A** and **B** backwards until horizontal
2. Open drain cock by pulling handle **C** backwards until horizontal and water should disappear
3. Blow through top cock by opening with handle **A** and close again
4. Blow through bottom cock by opening with handle **B** and close again
5. Shut drain cock with handle **C**
6. Open top cock and bottom cock with handles **A** and **B** and water should rise to level

TO TEST GAUGE COCKS

1. Shut top and bottom cocks by pulling handle **A** until it is pointing downwards halfway between the horizontal and vertical
2. Open drain cock by pulling handle **B** upwards until horizontal, and water should disappear
3. Open top and bottom cocks by raising handle **A** slowly until it is pointing upwards halfway between the horizontal and vertical in order to blow through, and close again
4. Shut drain cock by turning handle **B** downwards
5. Open top and bottom cocks with handle **A** until it is pointing upwards halfway between the horizontal and vertical and water should rise to level

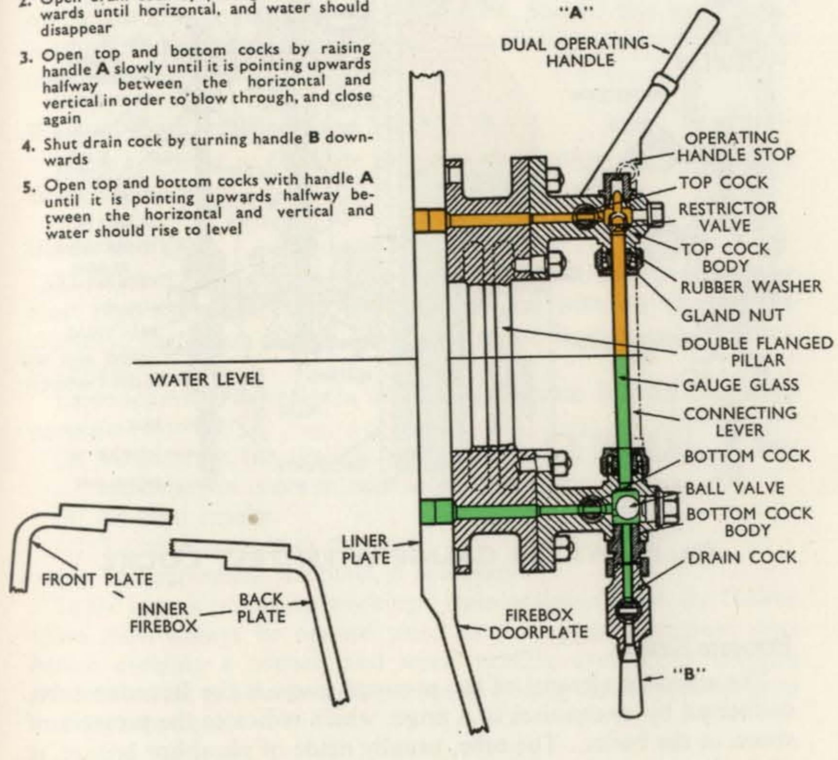


Fig. 18 WATER GAUGE TOP AND BOTTOM COCKS COUPLED

at the bottom of the glass, the firebox crown is covered.

When working under normal conditions the water should be kept in sight in the top half of the glass, and before descending severe gradients or working over curves with a large amount of superelevation a higher water level should be carried.

Normal running with too high a water level is detrimental to efficient locomotive performance in that a larger amount of water is carried over with the steam and the risk of priming is increased.

Types of water gauges are shown in Figs. 17, 18 and 19.

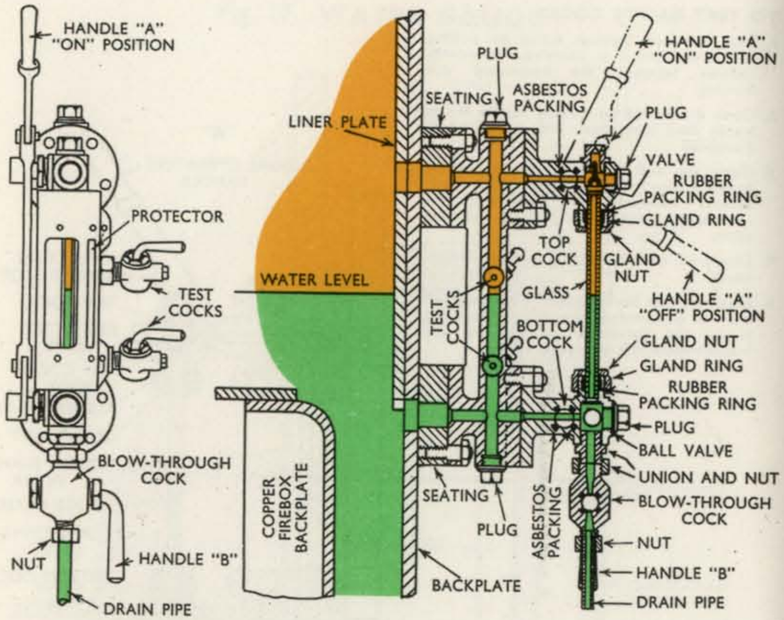


Fig. 19 WATER GAUGE WITH TEST COCKS

Pressure Gauge

The essential element of the pressure gauge is the Bourdon tube, connected by mechanism to a finger which indicates the pressure of steam in the boiler. The tube, usually made of phosphor bronze, is of oval cross-section and bent in the form of an arc of a circle, having one end fixed to a block which has a screw connection to the steam gauge pipe. The other end of the tube is sealed and is connected by a rod and pinion which magnifies the movement.

When pressure is applied, the tube tends to straighten out and the free end lifts by an amount proportional to the pressure applied by the steam.

Similarly, if a vacuum or negative pressure is applied the tube tends to close up and the pointer moves in the reverse direction as in a vacuum gauge.

Fusible Plugs

One or more fusible plugs are screwed into the firebox crown. These are of brass; some have a lead core which melts at a comparatively low temperature, and others have a brass button, secured by a lead filling.

If the water level in the boiler drops too low and uncovers the plugs, the lead melts and allows steam to escape into the firebox, which acts as a warning to the Enginemen. Should this occur both injectors should be immediately put on and steps taken to remove or deaden the fire.

Washout Plugs, Handhole and Mudhole Doors

These are fitted to facilitate periodical inspection and cleaning of the boiler water spaces.

Blower and Valve

The blower consists of a perforated ring fitted round the top of the blast pipe cap or, alternatively, cast integral with the base of the chimney, the steam supply being controlled from a valve on the footplate.

Its function is to create a smokebox vacuum for the following purposes:—

(*a*) To increase the draught on the fire when the locomotive is stationary in order to raise steam pressure.

(*b*) To clear smoke.

(*c*) To counteract back draught.

(*d*) To supplement the blast, if necessary.

In the case of (*c*), whilst working a train or light engine, the blower valve must always be opened prior to closing the regulator, also before entering a tunnel, and when passing over water troughs should be used as a further precaution to closing the ashpan dampers and firehole door.

Regulator Valves

Regulator valves of the vertical slide, horizontal slide balanced circular and double-beat types as well as the multiple-valve type in the superheater header are in common use on British Railways.

Vertical Slide-type Regulator

A typical vertical slide type is positioned in the dome as shown in Fig. 20. The regulator head usually has four ports, two small for starting purposes and two large size for normal running. The main valve, which has four ports, slides on its seating on the regulator head, and the pilot valve in turn seats upon the main valve, being held in position by a flat spring.

The first movement of the regulator handle lifts the pilot valve until the small ports are open. Further movement of the handle

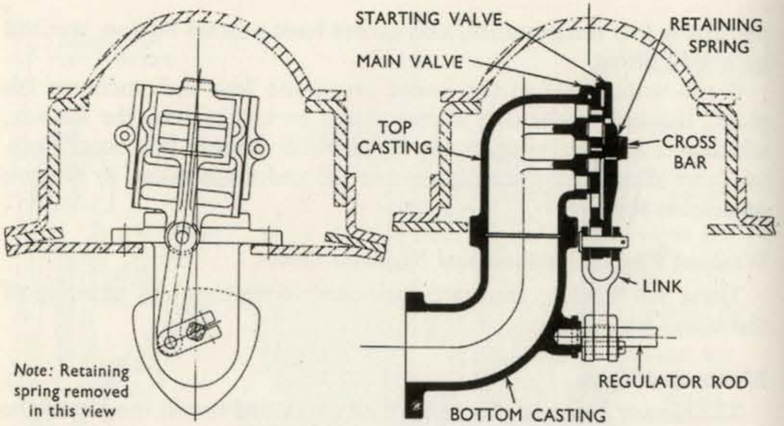


Fig. 20 REGULATOR VALVE VERTICAL DOME TYPE

moves both the pilot valve and the main valve together, which action opens the large ports and closes the starting ports. During closing, the pilot valve is first moved over the main valve to its normal closed position and then both valves are brought back together to their original position, closing the steam ports as they come down.

The independent movement of the pilot valve is obtained by the use of an elongated hole or slot in the main valve, the result being that the latter does not move until the pin has travelled a distance corresponding to the clearance of the slotted hole, a distance which is equal to the lap and port opening of the valve.

The pilot valve is provided to allow a gradual admission of steam into the main steam pipe so as to balance the pressure on the main valve, thus making easy and accurate adjustment possible.

Horizontal Dome-type Regulator

The horizontal slide dome type of regulator is shown in Fig. 21. It is similar in principle to the vertical pattern.

A main valve and pilot valve are employed, but the operating pin engages with slots formed in the raised sides of the valves. The slots in the main valve are wider than the diameter of the pin by an amount equal to the lap plus the port opening of the pilot valve.

Horizontal Regulator Smokebox Type

This regulator employs main and pilot valves similar to those of the dome type, but is positioned in the smokebox (see Fig. 10).

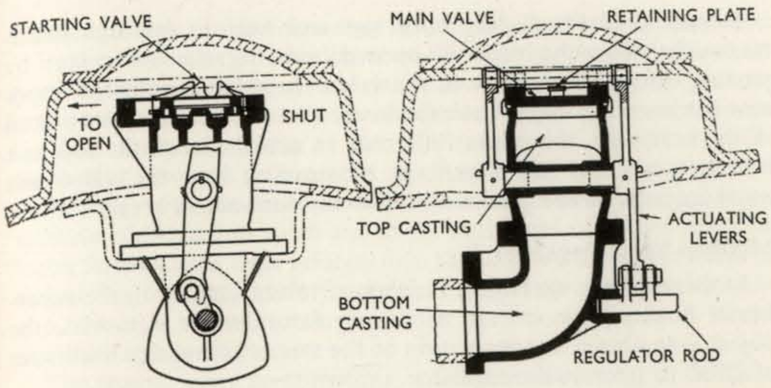


Fig. 21 REGULATOR VALVE HORIZONTAL DOME TYPE

Double-beat Type Regulator

The double-beat type of regulator valve is shown in Fig. 22.

This valve is mounted on a vertical cast-iron pipe in the dome. The valve is double, there being really two valves cast in one with two corresponding seats in the regulator head.

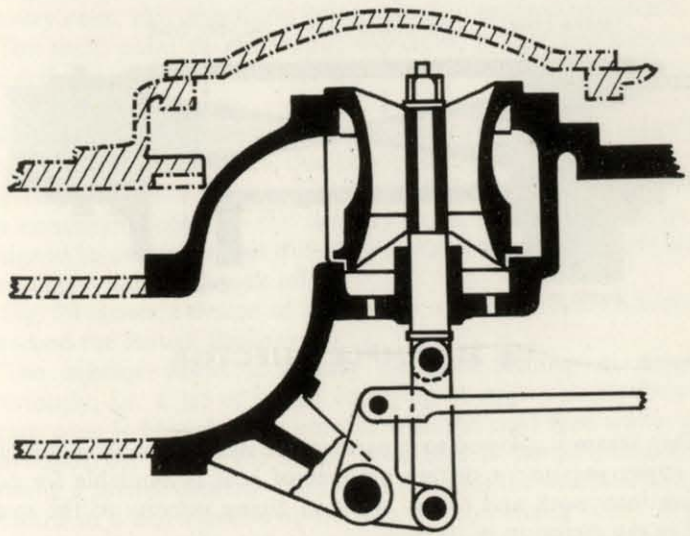


Fig. 22 DOUBLE-BEAT-TYPE REGULATOR VALVE

Steam is admitted past both top and bottom seatings simultaneously when the valve is opened, entering the lower seat by passing through the centre of the valve. In some designs the upper seat is somewhat larger than the lower seat to allow it to be placed in the head and, this slight difference in area between the top and bottom seats has the advantage of ensuring that the valve will move into the closed position should any connection break.

Multiple Valve Regulator

In this type of regulator a number of valves situated in the superheater header open in turn as the regulator handle is moved; the object is to obtain fine regulation of the steam flow with a minimum of effort to operate the regulator.

Injectors

The injector is an appliance for delivering feed water to a boiler. In its simplest form it embodies three essential cones, the "steam cone", the "combining cone" and the "delivery cone". The steam cone admits the steam to the injector, guides it in the direction in which it should flow, and limits, by its bore, the amount of steam passing through. Steam leaving this cone comes in contact with the water, is condensed by it and passes into the combining cone (Fig. 23).

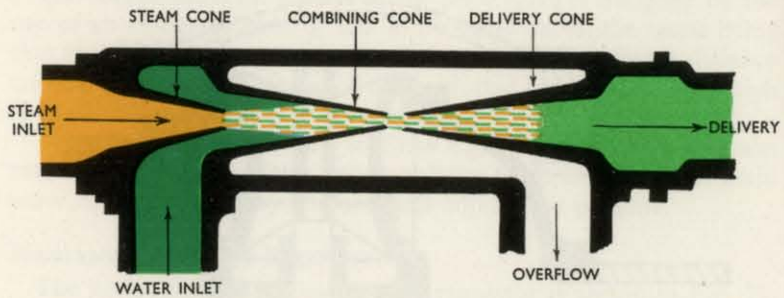


Fig. 23 SIMPLE INJECTOR

When steam is allowed to expand in the steam cone from a higher to a lower pressure a certain amount of heat is available for conversion into work and this is spent in giving velocity to the steam itself in the direction of its flow.

The first point to remember, therefore, is that the change from

pressure energy to velocity energy is brought about in the steam cone.

In the second or combining cone the slowly moving water combines with the swiftly moving steam, and the function of this cone is to ensure that the steam jet is condensed by the water. The cooler the feed water the better is the condensation of the steam. The combining cone is convergent in shape, the bore of the cone decreasing, with the result that the jet consists at its inlet end of a mixture of steam and water and at the outlet end of a solid jet of hot water flowing with high velocity into the delivery cone. Between the combining and the delivery cone is a gap, known as the overflow gap, through which excess steam and water are by-passed during the starting operation.

The second point to remember is that the combining cone effects the complete combination of the steam and water into the solid jet by the condensation of the steam and the transference of its energy to the water.

The delivery cone is so constructed that the change from velocity to pressure energy takes place as uniformly as possible. The momentum of the jet, which is greatest at the choke or smallest diameter of the delivery cone, is gradually reduced in velocity and increased in pressure sufficient to overcome the boiler pressure on the top of the clack valve. The temperature of the water is usually increased about 100°F. in passing through the injector. The size of an injector is determined by the throat or smallest diameter of the delivery cone, this dimension being stated in millimetres (mm.).

The third point to remember, therefore, is that the function of the delivery cone is to convert the velocity energy of the combined jet into pressure energy.

The early injectors described proved difficult to start and unreliable when used on locomotives, due to vibration, set up whilst running, affecting the combined jet of water and steam in its passage from the combining cone to the delivery cone. Modern injectors are designed to overcome this difficulty and automatically restart should they inadvertently "knock off".

Fig. 24 shows a design of an injector which has been adopted as standard for British Railways.

The injector works in exactly the same manner as described previously, i.e. a jet of steam emerging at high velocity from the steam cone is brought into contact with the cold feed water which surrounds the tip of the steam cone and is partially condensed, causing a partial vacuum. This in turn causes the water to be drawn forward at a considerable speed into the combining cone. Passage through this completes the condensation of the steam and at the same time it releases its velocity energy to the water which is forced

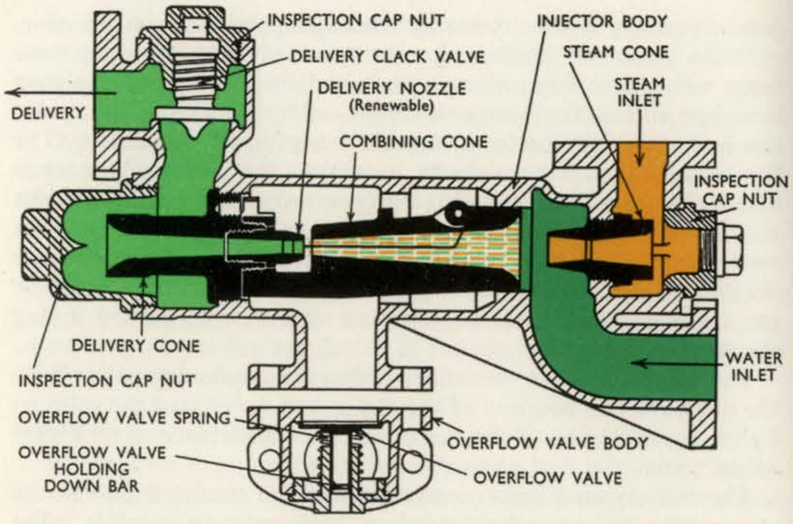


Fig. 24 INJECTOR COMBINING CONE WITH HINGED FLAP

forward at considerable speed through the small end of the cone. The water jet then jumps the overflow gap and enters a diverging delivery cone where the speed of flow and velocity energy, on its passage through the cone, exceeds the boiler pressure sufficiently to enable the feed water to lift the clack valve and enter the boiler. The upper portion of the combining cone is formed by a hinged flap, and the vacuum developed in the combining cone, when the injector is working, holds this flap against the fixed portion which then forms a continuous cone. If the action of the injector is interrupted or the water jet upset, the vacuum in this cone is replaced by a pressure which forces the hinged flap open, allowing any surplus steam and water to escape through the gap so formed to the overflow outlet. When the pressure has thus been relieved the working vacuum rapidly re-establishes itself and the injector will then start again.

Fig. 25 shows a type of injector which is fitted to large numbers of locomotives; in this arrangement the combining cone has a fixed and movable portion. In this arrangement the steam, during its passage along with the feed water through the combining cone, is fully condensed, causing a high vacuum which holds the movable portion of the cone in contact with the fixed portion, forming in effect one continuous cone; if, however, the action of the injector is interrupted or the water jet upset, the vacuum in the cone is replaced

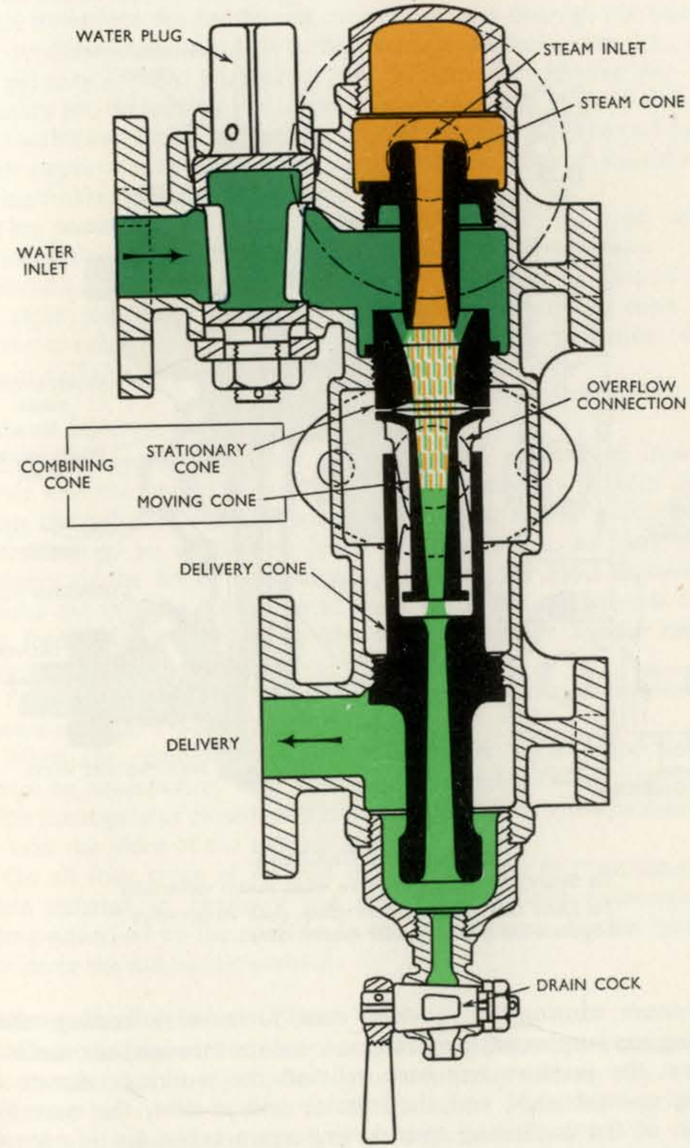
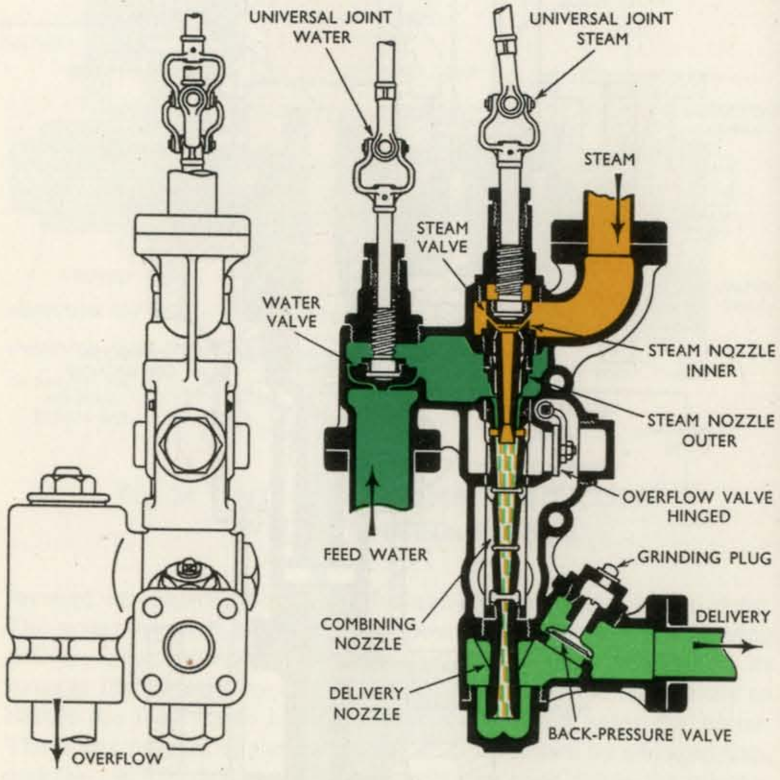


Fig. 25 INJECTOR COMBINING CONE FITTED WITH MOVABLE PORTION

Fig. 26 LIVE STEAM INJECTOR MONITOR TYPE



WORKING INSTRUCTIONS

To Start: Open water valve, then steam valve fully
To Shut Off: Close steam valve, then water valve
Regulate for quantity with water valve

by pressure causing the movable cone to leave its seating, thus allowing any surplus water and steam to escape through the overflow.

When the pressure has been relieved the working vacuum is quickly re-established and the injector will re-start, the movable portion of the combining cone having again taken up its normal working position.

One of the latest types of injectors is the "Monitor" type, as shown in Fig. 26 ; in this arrangement it will be noted that there are two steam cones and that the combining cone is without moving

parts, but is fitted with slots. When the water cock is opened, the water flows into the combining cone and passes through the slots to the overflow; when steam is turned on it is directed in two jets, first the primary annular jet, and second, the secondary forcing jet. The primary jet, on leaving the steam cone, comes into contact with the feed water and forces it down the combining cone past the end of the inner steam cone at which point the second jet of steam is introduced, giving further impulse to the combined jet.

The combined jet flows through the combining cone where condensation is completed and then enters the delivery cone.

Should interruption take place causing the injector to "knock off", the steam and water escape freely through the combining cone slots to the overflow until the jet is reformed by the condensation of the steam and the injector restarts.

Exhaust Injectors

Exhaust injectors provide an economical method of injecting water into the boiler by utilising a small amount of exhaust steam from the cylinder for this purpose. Exhaust steam which would otherwise go to waste also heats the feed water, so that a hot delivery to the boiler is obtained; therefore, for most economical results the injector should be at work when the regulator is open, the feed being regulated by the water regulator handle on the Fireman's side of the cab.

The "H", "J", "H/J" and "K" types of exhaust injector are shown in Figs. 27, 27A, 28, 28A and 29.

When the regulator is open the injector works with exhaust steam in conjunction with a supply of supplementary live steam. With the regulator closed, additional auxiliary live steam is necessary to take the place of the exhaust steam.

On all four types of exhaust injector mentioned the changeover from exhaust to auxiliary live steam is provided automatically, being governed by the pressure in the steam chest. Earlier types do not have the automatic control.

Steam-controlled Exhaust Steam Valve

When the locomotive is at work with regulator open, the exhaust steam valves in the injector are open, admitting exhaust steam to the injector; but if the injector is not in use or when the regulator is closed, the exhaust steam valves are automatically shut.

Auxiliary Shuttle Valve

This valve automatically controls the admission of steam to the injector, either exhaust steam or auxiliary live steam, according to

Fig. 27 EXHAUST INJECTOR ARRANGEMENT AND CONTROL CLASS "H"

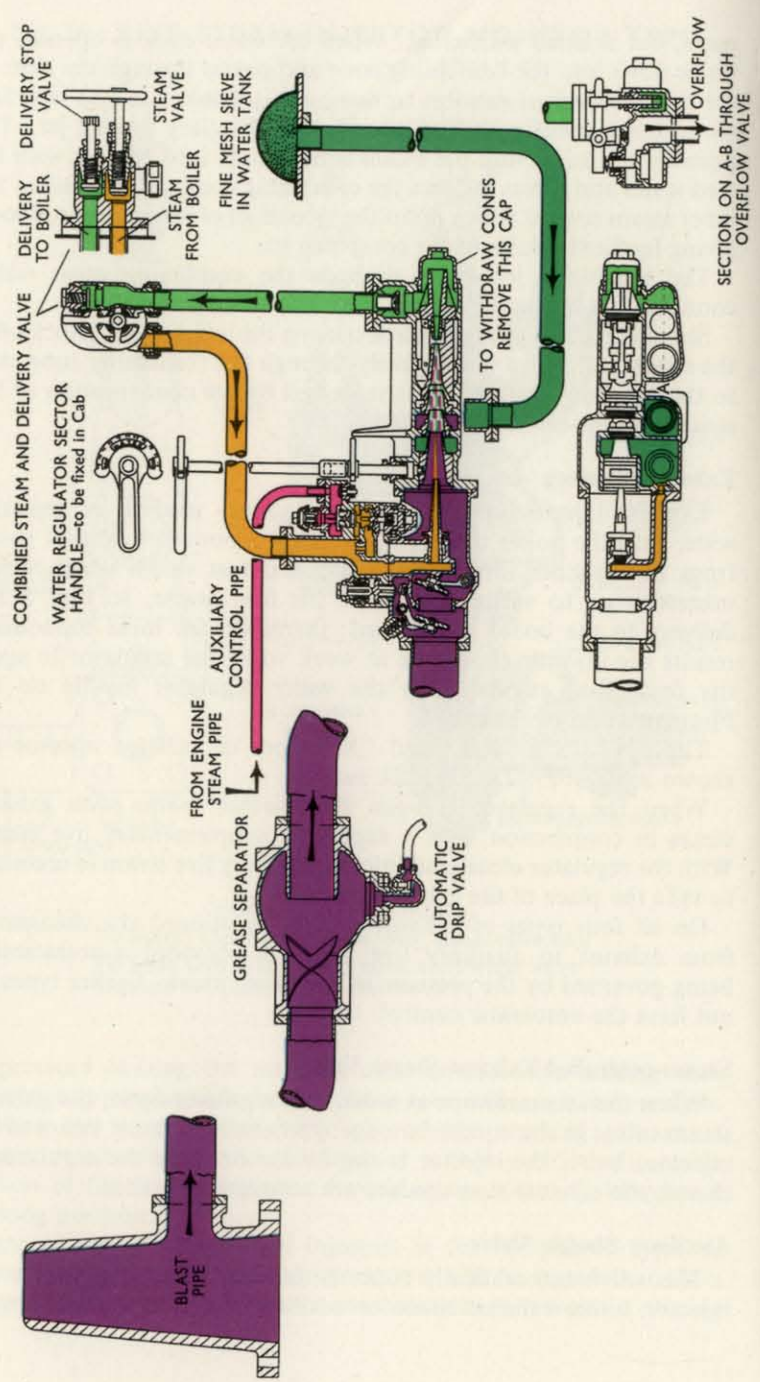
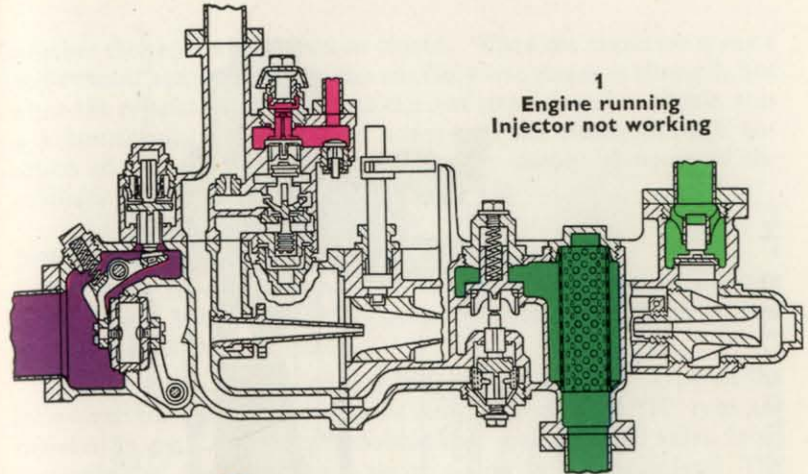
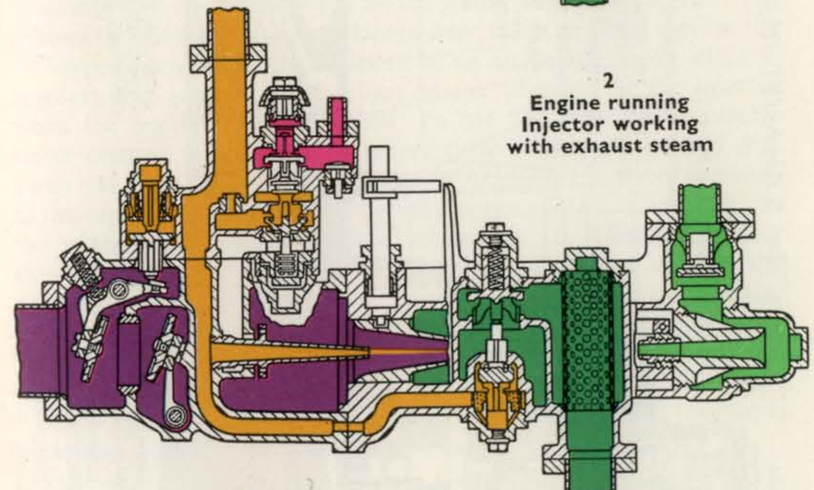


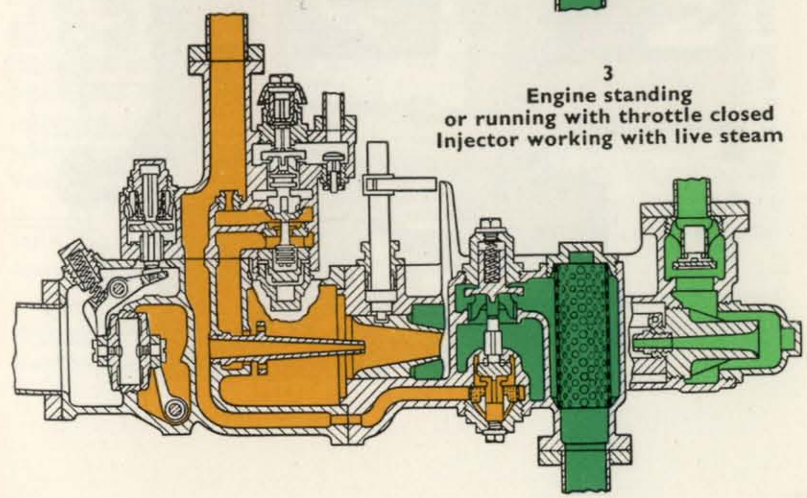
Fig. 27



1
Engine running
Injector not working

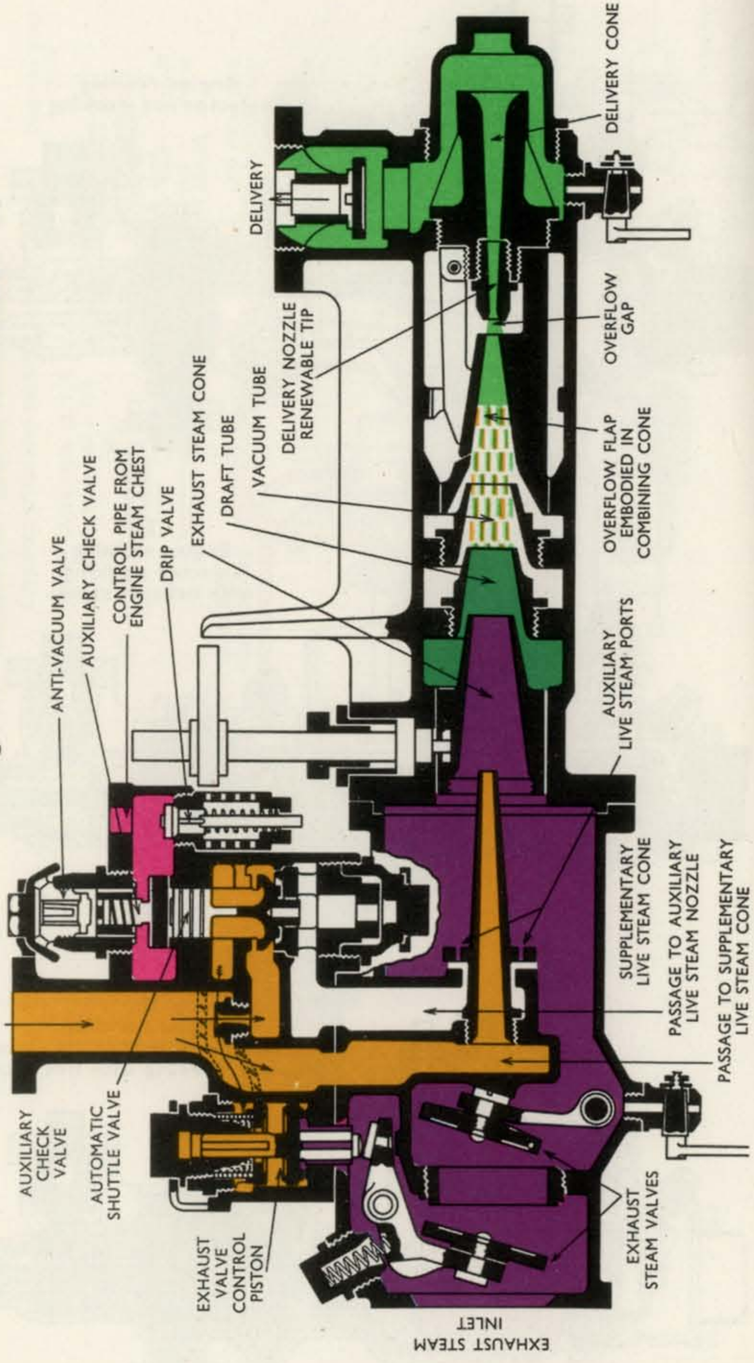


2
Engine running
Injector working
with exhaust steam



3
Engine standing
or running with throttle closed
Injector working with live steam

Fig. 27a EXHAUST INJECTOR CLASS "H"



whether the regulator is open or closed. When the regulator is open and exhaust steam available the auxiliary live steam is shut off, but when the regulator is closed and exhaust steam is not available, this is automatically replaced by a supply of live steam through the action of the shuttle valve controlling the supply of steam to the auxiliary live steam nozzle.

Steam-controlled Water Valve

The water valve is always in the shut position when the injector is not in use, but automatically opens immediately the steam valve is opened to start the injector.

The "J"-type exhaust injector differs from the "H" type in the following: the two pivoted exhaust steam valves in the "H" type are replaced in the "J" type by a double-beat spring-loaded valve fitted vertically and controlled by a steam piston below the valves. The automatic shuttle valve or change-over valve, is fitted below the "J"-type injector with the addition of an automatic choke valve to regulate the quantity of auxiliary steam supplied to the injector when the regulator valve is shut. In the "J" type the automatic water control valve has been replaced by a manual-operated disc water valve on the body of the injector or above the water entrance to the nozzles. This disc valve is fitted directly on to and worked by the water regulator spindle and rotated by it. The water valve merely acts as a water admission valve and does not regulate the quantity of water admitted to the injector cones, which is controlled by the movable exhaust steam cone as in the "H"-type injector. To shut off the "J"-type injector the steam valve is closed and the water regulator spindle moved to the shut position. In the "H/J" type the automatic water valve as on the "H" type is fitted to what is otherwise a "J" type injector.

The "K" type of exhaust injector is the latest design to be introduced and is fitted to the larger B.R. standard design of M.T. tender locomotives. In this design the movable exhaust steam cone, which has previously been used to control the amount of water delivered by the injector, has been replaced by a fixed exhaust steam cone and the water supply controlled by a variable water valve which is separate from the exhaust injector body but connected to it by an intermediate feed-water pipe. This arrangement enables both the injector and the water valve to be placed in accessible and convenient positions.

The "K"-type combining cone differs slightly from the previous designs in that in addition to the hinged overflow flap there are two overflow slots.

Fig. 28 EXHAUST INJECTOR CLASS "J"

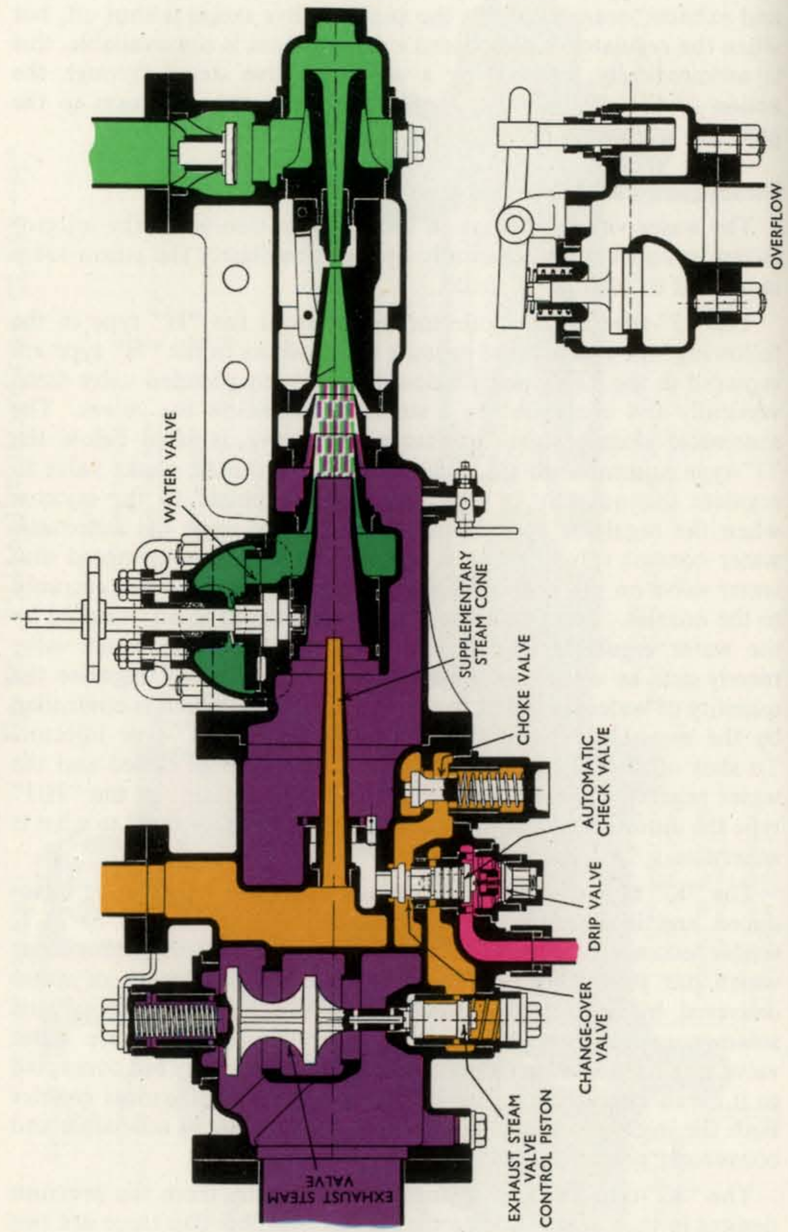
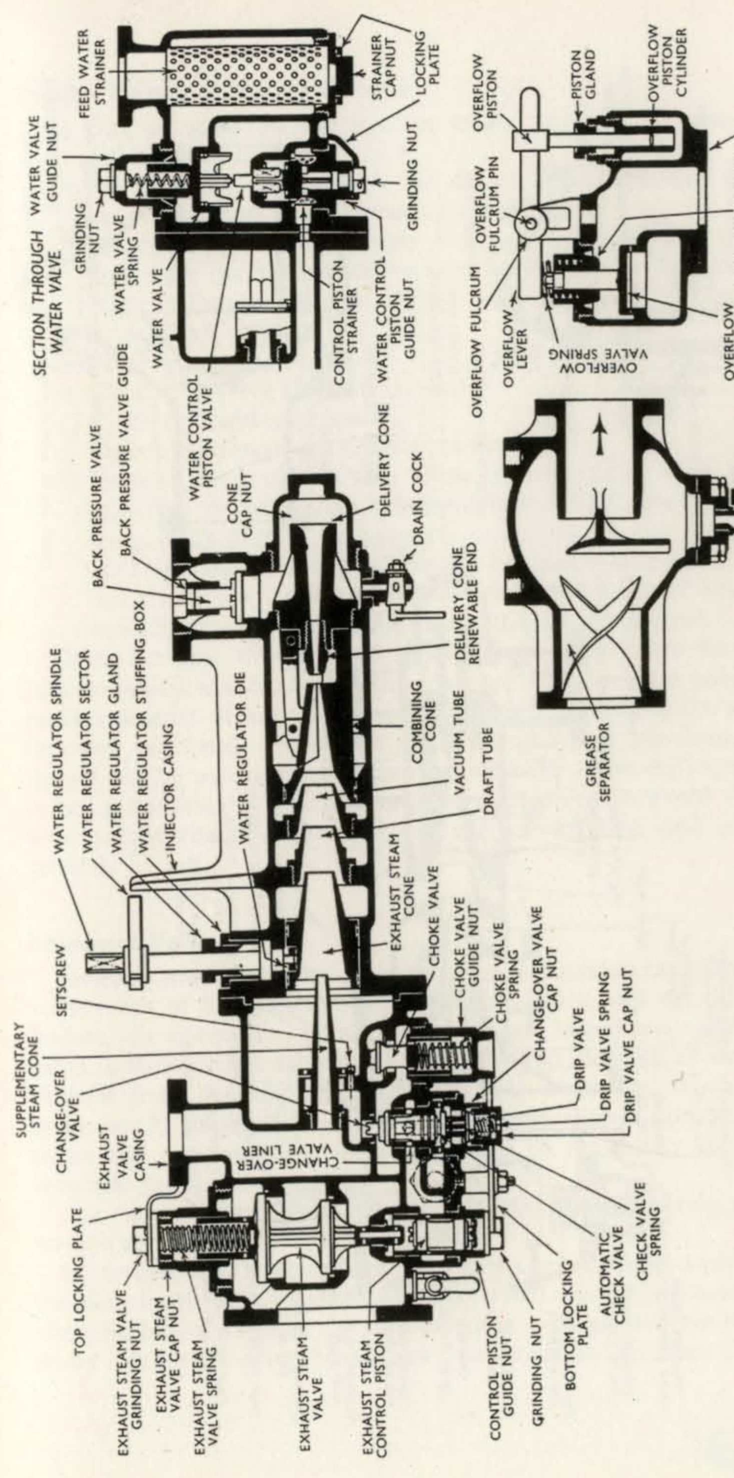


Fig. 28a EXHAUST INJECTOR CLASS "H/J"



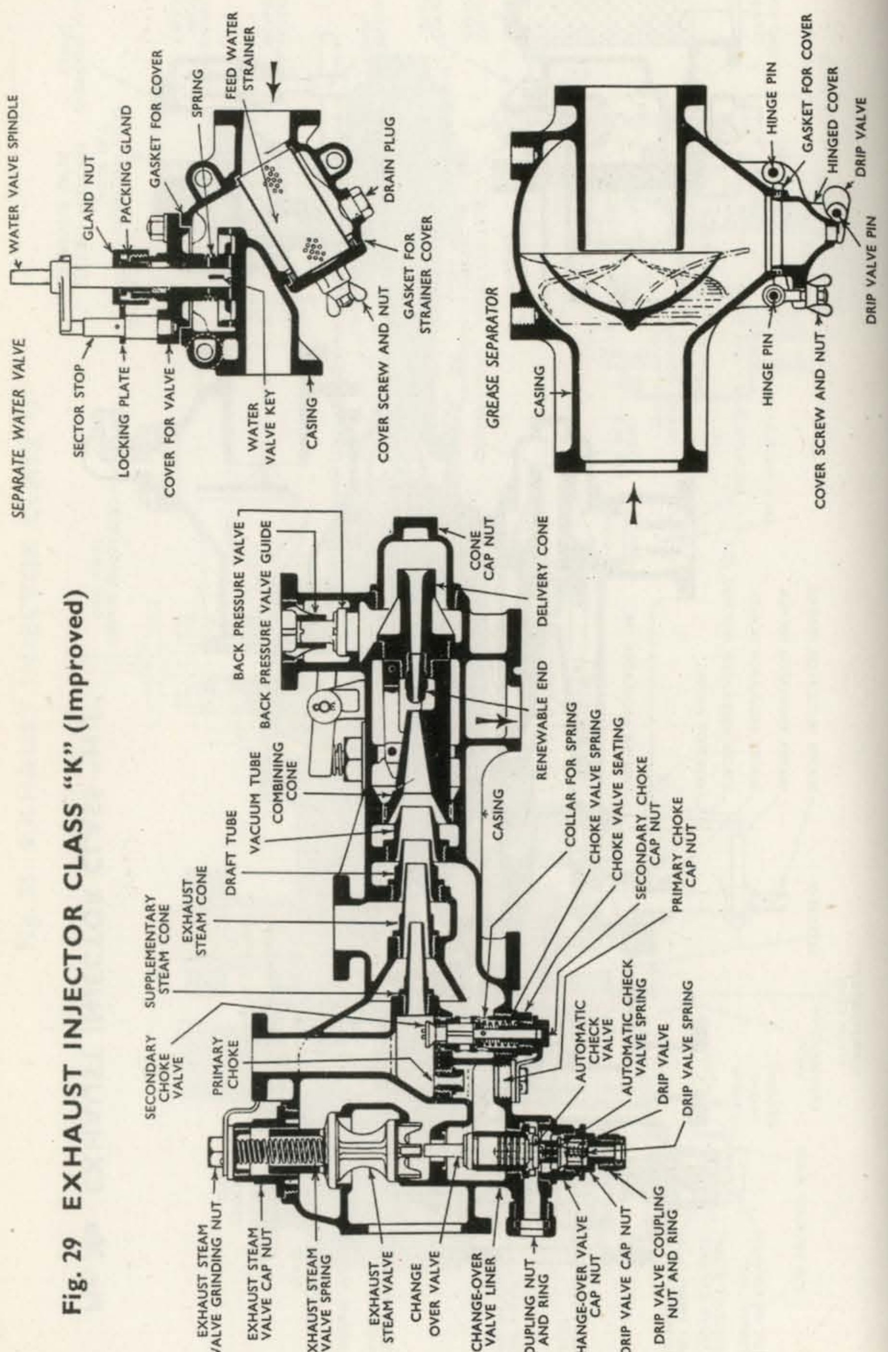


Fig. 29 EXHAUST INJECTOR CLASS "K" (Improved)

Possible Causes of Injector Failures

(*a*) Dirt or scale on the injector cones or excessive wear or distortion of the cones.

(*b*) Air leaks in water supply. Air drawn in with the feed water causing bubbles which break up the jet.

(*c*) Insufficient feed water supply owing to an obstruction in the tank sieve (as a preventative keep tank lid closed to prevent entry of foreign matter); supply valve not properly open or tender tank empty.

(*d*) Feed water too hot.

(*e*) Choked delivery pipe, due to scale.

(*f*) Clack not seating properly.

(*g*) Defect in connections to coal watering pipe.

(*h*) Some of these defects may allow the injector to work intermittently or at certain pressures only. Full details of the irregularity should be properly described on the "Repair" card for the guidance of Fitters, bearing in mind that it is not always easy to test an engine over its full range of working conditions when the locomotive is stabled in the shed.

There are few things more annoying to Enginemen than an injector which misbehaves on the journey; it is therefore policy to make a practice of using both injectors in turn where two live steam injectors are fitted. Where an exhaust injector is provided, this should not be used during shunting operations when the regulator is being continually opened and closed in order to avoid undue wear to the change-over valve and risk of scalding staff on the ground.

Blowdown Valves

Softened water for locomotive purposes is provided extensively in some areas of British Railways to reduce scaling and corrosion in boilers. In connection with this continuous blowdown valves are fitted to locomotives so that a small measured quantity of water is drained from the boiler continuously, (1) whilst the regulator is open, or (2) whilst the injectors are working. This is done to keep down the concentration of soluble salts in the boiler water to minimise priming.

The valve is fitted on the back plate of the firebox, having a connection above the crown (see Fig. 30).

In the case of (1), steam from the steam chest actuates a piston in the blowdown valve, which in turn lifts a ball valve from its seating, allowing boiler water at the rate of about 1-1½ gallons per minute to be discharged into the ashpan. On some locomotives (2) the

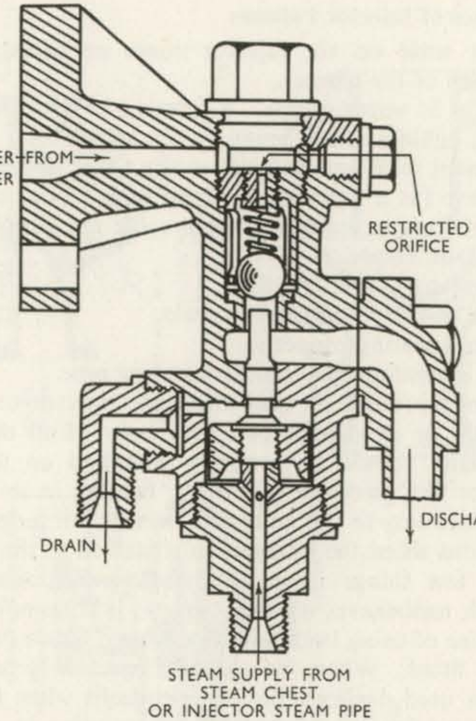


Fig. 30 CONTINUOUS BLOWDOWN VALVE

blowdown valve is operated by the pressure in either injector delivery pipe.

Carriage-warming Valve

This valve controls the pressure in the train-heating pipe.

Cab Fittings

Fig. 31 shows the arrangement of cab fittings on B.R. Standard locomotives.

Questions and Answers

(1) *Q.* What are the principal parts of a locomotive boiler?
A. Boiler barrel; outer and inner firebox; flue tubes; smokebox tubeplate; crown, firebox and longitudinal stays, dome, smokebox, superheater, brick arch, ashpan, firedoor and fusible plugs.

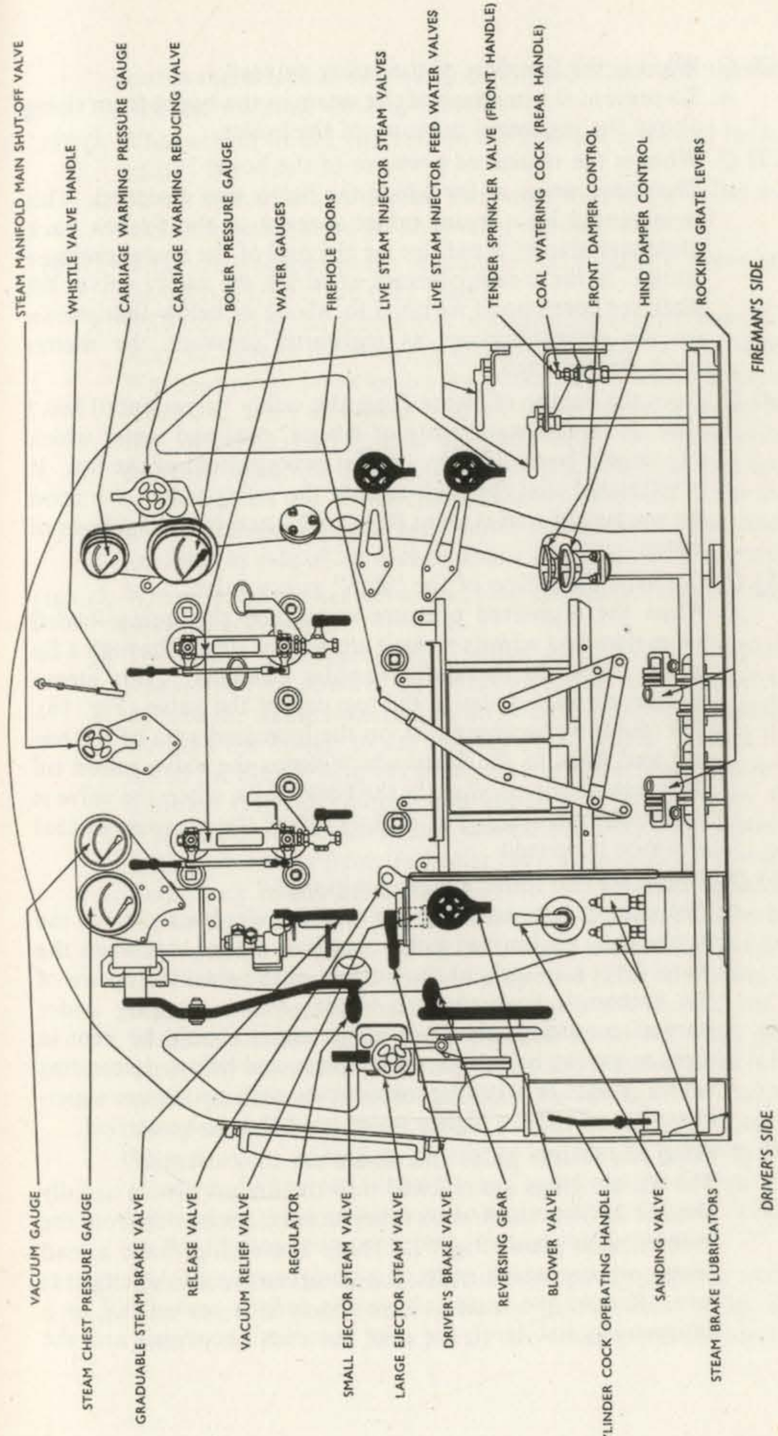


Fig. 31 ARRANGEMENT OF CAB FITTINGS
Standard Locomotive

Fig. 31

(2) *Q*. What is the function of the safety valves?
A. To prevent the pressure of the steam in the boiler from rising above the registered pressure of the boiler.

(3) *Q*. What is the registered pressure of the boiler?
A. The steam pressure for which the boiler was designed. This is indicated by a metal tablet secured to the firebox back plate and also by a red line on the dial of the steam pressure gauge. If the steam pressure at which the safety valves lift does not correspond within 5 lb. above or below that shown on the pressure gauge as registered pressure, the matter must be reported.

(4) *Q*. Does the escape of steam from the safety valves entail loss?
A. Yes. It represents a waste of labour, coal and water which can largely be avoided by careful management of the fire. It is estimated that for each minute the safety valves are open the wastage of coal is from 10 to 15 lbs. and over 10 gallons of water.

(5) *Q*. Describe the action of the "Pop" safety valve.
A. When the registered pressure is reached the spring-loaded valve rises and admits a small amount of steam through a lip in the valve to the outer annular chamber. This steam escapes through holes in the top cap of the valve (Fig. 16). The steam on escaping acts on the increased area of the top cap and adds to the force which keeps the valve raised till such time as the pressure in the boiler falls, when the valve is instantaneously closed at slightly below the pressure as that at which it opened.

(6) *Q*. Where are the water gauges positioned?
A. The water gauges are mounted on the boiler back plate in the engine cab; the bottom gauge cock is so placed that when the water level is in sight at the bottom of the glass the crown of the firebox is covered with water. When working under normal conditions the level of the water should be kept in sight in the top half of the gauge glass, and before descending severe grades or working over curves with maximum super-elevation of rails, a higher water level should be carried.

(7) *Q*. What are fusible plugs and where are they situated?
A. The fusible plugs are screwed into the firebox crown usually about 1 ft. from the firebox tubeplate and about 1 ft. from the firebox back plate (Fig. 7). These brass plugs have a lead centre or core which melts at a comparatively low temperature. Should the water above the firebox crown fall to a dangerously low level, the plug becomes uncovered and the lead is melted, thus admitting steam and water into the firebox and warning the Enginemen.

(8) *Q*. What action would you take in the event of a melted fusible plug?
A. Put on both injectors to raise the water level in the boiler and take immediate steps to remove or deaden the fire.

(9) *Q*. What are washout plugs, handhole and mudhole doors and for what purpose are they used?
A. Washout plugs, handhole and mudhole doors are removed at washout period for cleaning and examination of the boiler. Washout plugs are fitted on the boiler back plate, smokebox tubeplate, sides of firebox and on throat plate, also on top side of boiler barrel, near the feed trays, on taper boiler engines. Mudhole doors are usually fitted at front and back of the firebox just above the foundation ring and at the side of the firebox opposite each water space. Handhole doors are fitted at side of the firebox above the inside firebox crown.

(10) *Q*. Where is the blower valve and ring positioned and for what purpose is it used?
A. The blower valve is generally situated on the boiler back plate; steam from the dome is led to this valve and when the valve is opened the steam is carried by an internal steam pipe, passing through the boiler, to the smokebox tubeplate, whence it is led to the blower ring or casting on top of the blast pipe or to a blower ring cast integral with the base of the chimney. On B.R. standard locomotives it is mounted below the Driver's brake valve away from the boiler back plate so as to be within easy reach of the driver (see Fig. 21). The function of the blower is to create a partial vacuum in the smokebox when the regulator is closed. Whilst working a train or light engine, the blower valve must always be opened prior to closing the regulator to prevent back draught from the firebox and to avoid smokebox gases being induced down the blast pipe, especially on entering tunnels. Care should always be taken when passing over water troughs to see that the ashpan dampers and firedoor are closed (on the train engine) and the blower valve opened as a further caution to prevent back draught. When the locomotive is standing, the blower may be used to avoid smoke and to augment the natural draught in the firebox when required to raise steam pressure.

(11) *Q*. Describe how the vertical slide valve type of regulator works.
A. The valve is positioned vertically in the dome (Fig. 20); usually the face has four ports, two small ports for starting

purposes and two large ports for normal running. Resting on the valve face is the main valve which has four ports cut in it, and the pilot or starting valve rest in turn upon the main valve with a flat spring bearing against it. The pilot valve has usually two ports which are used for starting purposes.

The sequence of movements when operating the regulator is as follows: first movement of the regulator handle lifts the pilot valve until the two small starting ports are open. Further movement of the handle then moves both the pilot valve and the main valve together, which action opens the large ports in the main valve and closes the starting ports. During closing, the pilot valve is first moved down over the main valve to its normal position, and then both valves are brought back to their original position, closing the main ports as they come down.

The independent movement of the pilot valve is obtained by the use of a circular hole for the operating pin in the pilot valve and elongated hole or slot in the main valve, the result being that the latter does not move until the pin has travelled a distance corresponding to the clearance in the slotted hole, a distance which is equal to the lap plus the port of the pilot valve.

(12) *Q*. What purpose is served by the continuous blowdown valve?

A. To keep down the concentration of soluble salts in the boiler water on regions where water softening is in use, and this is done by allowing a small measured quantity of water to pass out of the boiler continuously whilst (*a*) the regulator is open, or (*b*) whilst injectors are working (Fig. 30). The use of this fitting, therefore, will tend to prevent priming.

(13) *Q*. What is the purpose of the manual-operated blowdown valve?

A. Whilst the continuous blowdown valve deals with dissolved solids in the water it does not assist with the discharge of the soft sludge which gradually accumulates in the bottom of the boiler barrel and firebox water spaces. To remove this sludge some locomotives are fitted with a manual-operated blowdown valve positioned just above the foundation ring at the centre of the firebox throat plate. This valve is operated by hand lever on the right side of the cab, separate instructions being issued for its use according to the district in which the locomotive may be working.

(14) *Q*. What is priming and foaming? What would you do when either occurs?

A. Priming is produced by certain conditions of the water as well as carrying a too high water level, and may be brought about by a sudden demand for steam which may result in syphoning action or it may be caused by uneven boiling. It is distinct from foaming in that it does not originate at the steaming surface, but at points below the water line. Foaming consists of an aggregation of bubbles which carry the sediment to the surface of the water. In both cases water is carried over with the steam to the cylinders. The more serious effects of priming and foaming in locomotive boilers are the impairment of lubrication due to water and suspended matter passing into the cylinders: interference with the proper functioning of the superheater, due to accumulation of water which must be evaporated before increase of temperature can take place, and in addition the superheater elements may be fouled with solid matter. The water accumulated in the cylinders may also cause damage to the cylinders and motion of the engine.

When priming and foaming occurs with a low water level, open the cylinder cocks, put on the injectors and close the regulator gently until the water settles in the boiler to ascertain the water level, as there is danger of exposing the firebox crown.

(15) *Q*. What is the purpose of feed-water treatment?

A. All natural water contains suspended and dissolved matter, the most common being the acid salts of calcium and magnesium. Treating boiler feed water brings about the precipitation of scale-forming salts which causes the resulting suspended matter to be of such form as to be readily removed as a sludge, thereby keeping the firebox plates and tubes in a much cleaner condition than is the case when untreated water containing scale-forming salts is used.

(16) *Q*. What is the best system for using injectors?

A. Where two live steam injectors are fitted they should always be used in turn to keep both in working order.

(17) *Q*. What depth of water should be maintained in the boiler as a good working level?

A. To maintain the water level in the gauge glass at half to three-quarters full is best. This provides a good depth of water over the firebox and at the same time leaves plenty of steam space.

(18) *Q*. What ill-effects will result from having too much water in the boiler?

A. Too high water level in the boiler is bad practice. It restricts the steam space and leads to water being carried over with the steam, which may cause such troubles as damaged cylinders and pistons, bent connecting rods, possible difficulty in releasing the vacuum brake, and injector troubles.

(19) *Q*. Explain the working principles of a movable combining-cone type of injector.

A. Fig. 25 shows this injector which is usually placed vertically at the inside of the trailing engine footstep. A jet of steam emerging at high velocity from the (top) steam cone is brought into contact with the cold feed water which is admitted round the tip of the steam cone. Partial condensation of the steam jet takes place, a partial vacuum is formed, and the water is forced forward at considerable speed into the wide end of the converging combining cone. Passage through this cone completes the condensation of the steam, producing a high vacuum, and the water emerges from the small end of the cone at greatly increased velocity. The water jet then passes the overflow gap and enters a diverging cone known as the delivery cone.

The shape of the delivery cone causes the speed of the flow to be quickly and considerably reduced, which process converts the energy of motion in the water into pressure energy at the outlet end of the delivery cone. The pressure developed in this way at the delivery end of the injector exceeds the boiler pressure sufficiently to enable the feed water to lift the clack valve against the steam pressure and enter the boiler.

The vacuum developed in the combining cone when the injector is working is used to hold a movable section of the cone up against the top portion, giving the effect of a continuous cone. If the action of the injector is interrupted or the water jet upset, the vacuum in the cone is replaced by pressure, the moving section is then forced away from its seating and any surplus steam and water escapes through the gap so formed, to the overflow outlet. When the pressure has been relieved the working vacuum rapidly re-establishes itself and the injector will then restart. In some types of injectors the moving cone is replaced by a hinged flap forming one side of the combining cone. In this case the flap is forced open when the injector "flies off". Injectors with sliding cone or hinged flap are known as automatic restarting injectors.

(20) *Q*. What is the purpose of the exhaust steam injector?

A. To provide an economical method of injecting water into the boiler by utilising steam from the blast pipe for this purpose. Exhaust steam also heats the feed water so that a hot feed is obtained. For best results the injector should be at work when the regulator is open, the feed being regulated by the handle provided. The hottest feed is obtained when the feed handle is in the "minimum" position.

(21) *Q*. Name the cones in the exhaust injector.

A. Supplementary live steam cone, movable exhaust steam cone for regulating water supply (except in the "K" type), draft tube, vacuum tube, combining cone and delivery cone. There is also the auxiliary live steam nozzle, and ports around the supplementary cone.

(22) *Q*. What are the main differences between the "H" and "J" types of exhaust steam injectors?

A. The two pivoted exhaust steam valves in the "H" type are replaced in the "J" type by a double-beat spring-loaded valve fitted vertically and controlled by a steam piston below the valve. The automatic shuttle valve or change-over valve is fitted below the "J"-type injector with the addition of an automatic choke valve to regulate the quantity of auxiliary steam supplied to the injector when the regulator valve is shut. In the "J" type the automatic water control valve has been replaced by a manual-operated disc water valve on the body of the injector above the water entrance to the nozzles. This disc valve is fitted directly on to and worked by the water regulator spindle and rotated by it. The water valve merely acts as a water-admission valve and does not regulate the quantity of water admitted to the injector cones, which is controlled by the movable exhaust steam cone as in the "H"-type injector. To shut off the "J"-type injector the steam valve is closed and the water regulator spindle moved to the shut position.

(23) *Q*. What is the "H/J" exhaust steam injector?

A. This is an exhaust injector of the "H" type retaining the automatic water control valve but embracing the front or live and exhaust steam portion of the "J" type, i.e. the casting containing the exhaust steam control, change-over control system and automatic choke valve. The main body of the injector, containing the cones, automatic water valve and details of the "H" type, is retained.

(24) *Q*. How would you test the automatic change-over in the exhaust steam injector?

A. To test the automatic change-over from live steam to exhaust steam and vice versa apply engine brake with engine standing, start injector working and then open engine regulator. If the automatic shuttle valve functions properly the injector will stop working and water will run out of overflow. Then close the regulator and open the cylinder cocks. When pressure has escaped from the engine cylinders the injector will immediately work. If the injector does not operate as described and continues to work with the regulator open, the automatic shuttle valve does not function. Either a restriction will be found in the auxiliary steam pipe from the steam chest to the injector or the automatic check valve does not seat properly.

(25) *Q*. If the auxiliary control pipe from the steam chest breaks while running, what should be done?

A. If possible, carry on to first stopping point then blank off the pipe at a union or close isolating cock where fitted; if unable to do this, flatten the pipe on the steam chest side of the fracture. The injector will still work on live steam with this pipe blanked off. If the exhaust steam pipe, from the blast pipe to the injector, fractures whilst running, the auxiliary control pipe from the steam chest would have to be blanked off to allow the injector to operate with live steam while regulator valve was open, although injector would work normally with regulator closed.

(26) *Q*. If one of the top feed clacks sticks up when working a train, what steps would you take?

A. Immediately put on the opposite injector and then note whether the boiler will supply the demand for steam required to work the train in addition to the loss from the sticking clack. If it will not, the train should be stopped at next point where it can be placed under protection of fixed signals, where steps should be taken to re-seat the clack. To do this, close the tank or tender feed valve and the blow-back steam will exhaust at the injector overflow; open the water regulator valve wide; open the injector steam valve fully to expel the blow-back steam and to create a partial vacuum in the injector body; open the tank feed quickly and the injector should pick up the water and, when regulated, the delivery will disturb the clack which should re-seat when the injector is shut off.

(27) *Q*. If your engine is giving trouble with leaking tubes or stays, what is the best procedure to adopt?

A. In this case the Driver should do all in his power to ease the demand on the boiler and assist the Fireman by working the engine as lightly as possible. It is better to lose a few minutes in running than to come to a forced stop in a section, thereby causing heavy delays by having to carry out Protection Rules. The Fireman should exercise the greatest care in manipulation of the injector, dampers and firedoor, in order to maintain the firebox temperature as steady as possible.

(28) *Q*. Name several preventable causes of engines not steaming.

A. Dirty firebox tubeplate, tubes blocked up, leaking joints in smokebox, tubes leaking, blast pipe out of alignment with chimney, smokebox door drawing air (not properly tightened up), defective brick arch, defective dampers, valves and pistons blowing through, inefficient firing, badly fitting baffle plate and choked ash plate (spark arrester) in smokebox of the self-cleaning type.