ON THE USE OF PETROLEUM REFUSE AS FUEL IN LOCOMOTIVE ENGINES.

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The object of the present paper is to bring before the Institution the results of the author's experience in the extensive use of Petroleum Refuse as fuel in the locomotives under his charge on the Grazi and Tsaritsin Railway, South East Russia. In 1874 the first experiments in Russia with petroleum as fuel for locomotives were made on this railway;* but owing to its great cost at that time, although found in other respects capable of being used as a fuel, it was abandoned as uneconomical. Recently several appliances, the details of which are sufficiently well known, have been invented for utilising liquid fuel for locomotive and other boilers, and have been attended with more or less success.† A few of the most approved plans were tested on the Grazi and Tsaritsin Railway under the author's superintendence, thus affording him an excellent opportunity of becoming thoroughly acquainted with their working.

Petroleum.—The capabilities of liquid hydro-carbon as fuel, and the method of its employment, are but little known in Europe, its use being confined almost entirely to South East Russia, the only country in the continent of Europe where it is found in very great quantities. Besides Russia, the chief countries in which it is at present found are North America, Roumania, Hanover, Burmah (Rangoon), Australia, Galicia, and Africa; but where it may ultimately be found in large quantities it is difficult to say. Crude petroleum is found in large quantities at Baku on the south western shore of the Caspian Sea. The method invariably followed for its extraction is

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* See Mr. Harrison Aydon's paper on Liquid Fuels, Institution of Civil Engineers, Proceedings 1878, vol. lii., page 188.

† See "Engineering" of 22 and 29 June 1883, pages 578 and 600.

to sink a bore-hole similar to an artesian well, but of larger dimensions. Cases occur almost annually of petroleum gushing forth from the wells like a fountain and under great pressure, spouting sometimes to a height of from 50 to 75 feet with a diameter at its issue of from 10 to 15 inches. Such a fountain flows uncontrollably for weeks together, flooding all the immediate vicinity and forming regular lakes of petroleum. This oil is called "lake petroleum," and has the peculiarity that the more volatile matter evaporates after some time of settling, and what is left is not so gaseous. At Balaxna (Black Town), near Baku, there are many large distilling establishments for manufacturing kerosine, benzine, photogen, &c., from crude petroleum. The by-products or refuse are used for the manufacture of lubricating oils, but more generally as fuel. In Russia the quantity of refuse in proportion to the distilled kerosine is very great; the finest kerosine amounts to only about 25 per cent. of the original weight of crude oil used, and ordinary commercial kerosine to only about 30 per cent., the remaining 70 to 75 per cent. being therefore available as fuel. Throughout the present paper it will be understood that the petroleum refuse spoken of by the writer as burnt in his locomotives is the first residue after the kerosine oil for burning in lamps has been distilled off; it is generally known in Russia as naphtha residue or refuse. Whether owing to the original chemical composition of raw petroleum or to the method of kerosine manufacture, the results are very different in America; there ordinary kerosine for illuminating purposes as produced from the Pennsylvanian crude oil amounts to from 70 to 75 per cent. of crude oil used. Yet the chemical composition of Pennsylvanian and of Russian crude oil is so nearly the same, as seen by the comparative statement tabulated below, that such a great difference would scarcely be expected in the distilled product, if the crude oil were treated in a similar manner.

Much has already been published as to the efficiency of hydro-carbon liquid fuels; but the writer is of opinion that a good deal remains to be made clear on the subject. Comparing naphtha refuse and anthracite, the former has a theoretical evaporative power of

Pennsylvanian and Russian Crude Petroleum Oil.

Crude Petroleum Oil.	PENNSYLVANIAN.	RUSSIAN.		
		Light.	Heavy.	Naphtha Refuse.
	per cent.	per cent.	per cent.	per cent.
Carbon . . .	84·9	86·3	86·6	87·1
Hydrogen . .	13·7	13·6	12·3	11·7
Oxygen . . .	1·4	0·1	1·1	1·2
	100·0	100·0	100·0	100·0
Specific Gravity at 32° Fahr. (water = 1·000) . .	0·886	0·884	0·938	0·928
Heating Power, British thermal units . . .	19,210 units	22,628 units	19,440 units	19,260 units
Theoretical Evaporation at 8 atm. pressure, in lbs. of water per lb. of fuel	16·2 lbs.	17·4 lbs.	16·4 lbs.	16·2 lbs.

16·2 lbs. of water per lb. of fuel, and the latter of 12·2 lbs., at an effective pressure of 8 atm. or 120 lbs. per sq. inch; hence petroleum has, weight for weight, 33 per cent. higher evaporative value than anthracite. Now in locomotive practice a mean evaporation of from 7 to 7½ lbs. of water per lb. of anthracite is about what is generally obtained, thus giving about 60 per cent. of efficiency, while 40 per cent. of the heating power is unavoidably lost. But with petroleum an evaporation of 12·25 lbs. is practically obtained, giving $\frac{12 \cdot 25}{16 \cdot 2}$ = 75 per cent. efficiency. Thus in the first place petroleum is theoretically 33 per cent. superior to anthracite in evaporative power; and secondly, its useful effect is 15 per cent. greater, being 75 per cent. instead of 60 per cent.; while thirdly, weight for weight, the practical evaporative value of petroleum must be reckoned as at least from $\frac{12 \cdot 25 - 7 \cdot 50}{7 \cdot 50} = 63$ per cent. to $\frac{12 \cdot 25 - 7 \cdot 00}{7 \cdot 00} = 75$ per cent. higher than that of anthracite.

Spray Injector.—Steam, not superheated, being the most convenient for injecting the spray of liquid fuel into the furnace, it remains to be proved how far superheated steam or compressed air is really superior to ordinary saturated steam, taken from the highest point inside the boiler by a special internal pipe. In using several systems of spray injectors for locomotives, the author invariably noticed the impossibility of preventing leakage of tubes, accumulation of soot, and inequality of heating of the fire-box. The work of a locomotive boiler is very different from that of a marine or stationary boiler, owing to the frequent changes of gradient on the line, and the frequent stoppages at stations. These conditions render firing with petroleum very difficult; and were it not for the part played by properly arranged brickwork inside the fire-box, the spray jet alone would be quite inadequate.

Hitherto the efforts of engineers have been mainly directed towards arriving at the best kind of "spray injector," for so minutely subdividing a jet of petroleum into a fine spray, by the aid of steam or compressed air, as to render it inflammable and of easy ignition. For this object nearly all the known spray-injectors have very long and narrow orifices for petroleum as well as for steam; the width of the orifices does not exceed from ½ mm. to 2 mm. or 0·02 to 0·08 inch, and in many instances is capable of adjustment. With such narrow orifices it is clear that any small solid particles which may find their way into the spray-injector along with the petroleum will foul the nozzle and check the fire. Hence in many of the steamboats on the Caspian Sea, although a single spray-injector suffices for one furnace, two are used, in order that when one gets fouled the other may still work; but of course the fouled orifices require incessant cleaning out.

The construction of the spray-injector, as shown in Figs. 16 and 17, Plate 57, is very simple; in fact its great simplicity is its peculiar feature, and its merit is enhanced by the facilities it affords for stopping the fire at a moment's notice, as well as for regulating it to the utmost nicety during running or when standing at stations, in accordance with the demands made upon the boiler.

The combustion chamber, shown in Figs. 7, 8, and 11, Plates 54 and 56, is constructed with brickwork inside it, which when heated acts as a regenerator; through the brickwork are made as many channels or gas passages as are compatible with a sufficiently substantial structure. The brickwork thus offers a slight resistance to the free exit of the ignited gases, and so retains them as long a time as possible in the combustion chamber and fire-box, securing their thorough admixture with the air, as well as a long circuit before they enter the tubes.

The several drawings, Figs. 7 to 12, Plates 54 to 56, represent the arrangements adopted for securing the best results, the principle remaining the same in every case. Figs. 7, 8, and 11 show the plan that is found one of the best suited for locomotives. In Figs. 9, 10, and 12 is shown an arrangement intended for heating as hot as possible the portion of air that is introduced through the forward ash-pan damper, by passing it up through a narrow vertical channel A in the brickwork; an appreciable difference in results has been noticed with this method, simply from the fact that the air is considerably heated.

The only instance in which the author is using cold air for diffusing the spray is in the case of a special fire, shown in Figs. 20 and 21, Plate 59, arranged without a regenerator, for heating tyres; the ordinary blast is employed from the smithy main, being supplied by a Root's blower. In this arrangement the cost for fuel is only one-third of what it used to be with bituminous coal, while the amount of work done per day has been increased by 25 per cent. The four spray nozzles are arranged tangentially to the tyre, thus securing a circulation of flame all round. The appliances used for this open petroleum fire were not specially made for the purpose; the boxes previously employed for coal, shown in Figs. 22 and 23, were merely arranged to suit petroleum; the drawing therefore simply shows the main principle.

Locomotives.—In arranging a locomotive for burning petroleum, several details are required to be added in order to render the application convenient. In the first place, for getting up steam to begin with, a gas-pipe G, Fig. 3, Plate 51, of 1 inch internal diameter is fixed along the outside of the boiler; and towards the middle of its length it is fitted with a three-way cock N having a screw-nipple and cap. The front end of the longitudinal pipe G is connected to the blower in the chimney, and the back end is attached to the spray injector. Then by connecting to the nipple N a pipe from a shunting locomotive under steam, the spray jet is immediately started by the borrowed steam, by which at the same time a draught is also maintained in the chimney. In a fully equipped engine-shed the borrowed steam would be obtained from a fixed boiler conveniently placed and specially arranged for the purpose of raising steam. In practice steam can be raised from cold water to 3 atm. pressure (45 lbs. per sq. inch) in twenty minutes. The use of auxiliary steam is then dispensed with, and the spray jet is worked by steam from its own boiler; a pressure of 8 atm. (120 lbs.) is thus obtained in 50 to 55 minutes from the time the spray jet was first started. In daily practice, when it is only necessary to raise steam in boilers already full of hot water, the full pressure of 7 to 8 atm. is obtained in from 20 to 25 minutes.

While experimenting with liquid fuel for locomotives, a separate tank was placed on the tender for carrying the petroleum, having a capacity of about 3 tons. But to have a separate tank on the tender, even though fixed in place, would be a source of danger, from the possibility of its moving forwards in case of collision. It was therefore decided, as soon as petroleum firing was permanently introduced, to place the tank for fuel in the tender between the two side compartments of the water-tank, as shown in Fig. 5, Plate 53, utilising the original coal-space. In this way a considerable saving in cost is obtained, besides greater safety. As three sides of the petroleum tank already existed, all that was required was to put a bulkhead in front, and to plate the top and bottom, thus giving the tender a flat top or platform appearance. One advantage arising from this arrangement is that in winter, while heating the water in the tender, the heat is transmitted to the petroleum through the two sides and rear end of the tank. But in addition it is also indispensable to place a warming coil of steam-pipe C close by the

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outlet oil-valve V in the tank; through this coil a constant small upward flow of steam is maintained, entering at the bottom, and issuing into the air at T at one side of the top of the tender, so that the driver can always see that steam is really passing through the coil. This warming is always necessary when the air-temperature falls to about 12° Fahr. below freezing point. The small warming pipe S supplying steam to the coil has an elastic connection between tender and engine, and runs along inside the straight part of the main petroleum pipe P. (See discussion, page 329.)

The petroleum is transported from Baku in tanks; and in some cases wooden barges, which were not specially prepared for the purpose, are filled with petroleum. Thus a great quantity of water gets mixed up with the petroleum by leakage, &c. So long as the petroleum is cold, say below freezing point, the water does not easily separate from it. But whenever the petroleum is warmed up, say to 50° Fahr., the water separates very readily. On each tender-tank is therefore placed a water collector, as shown at W in Fig. 5, Plate 53, having a cock for letting the water off occasionally as it accumulates.

Each tender-tank is also fitted with a gauge-glass of 1 inch diameter, having a scale of inches graduated on a wooden frame that is used to stiffen the glass, which is over 4 feet long. By means of the gauge-glass, the engine-driver can see how the petroleum goes, each inch on the gauge being equivalent to so many poods or lbs.; the tanks being of rectangular form, their area is the same top and bottom. For a six-wheeled locomotive the capacity of the tank is $3\frac{1}{2}$ tons of oil,—a quantity sufficient for 250 miles, with a train of 480 tons gross, exclusive of engine and tender.

In charging the tender-tank with petroleum it is of great importance to have strainers of wire cloth in the manhole M, Fig. 5, Plate 53, of two different meshes, the outer one having openings say of $\frac{1}{4}$ inch, the inner say of $\frac{1}{8}$ inch; these strainers are occasionally taken out and cleaned. If care be taken to prevent any solid particles from entering with the petroleum, no fouling of the spray injector is likely to occur; and even if an obstruction should arise, the obstacle being of small size can easily be blown through by screwing back the steam cone in the spray injector, Fig. 17, Plate 57, far enough to let the solid particles pass and be blown out into the fire-box by the steam. This expedient is easily resorted to even when running; and no more inconvenience arises than an extra puff of dense smoke for a moment, in consequence of the sudden admission of too much fuel.

Besides the two strainers in the manhole M of the petroleum tank on the tender, there should be another strainer inside the tank at the outlet valve V, as shown in Fig. 5, Plate 53, having a mesh of $\frac{1}{8}$ inch holes.

Driving of Locomotives.—In lighting up, certain precise rules have to be followed, in order to prevent explosion of any gas that may have accumulated in the fire-box. Such explosions do often take place in cases of negligence; but they amount simply to a puff of gas, driving smoke out through the ash-pan dampers, without any disagreeably loud report; this is all prevented by adhering to the following simple rules. First clear the spray-nozzle of water, by letting a small quantity of steam blow through, with the ash-pan doors open; at the same time start the blower in the chimney for a few seconds, and the gas, if any, will be immediately drawn up the chimney. Next place on the bottom of the combustion chamber a piece of cotton waste, or a handful of shavings, saturated with petroleum, and burning with a flame. Then by opening first the steam-valve of the spray injector, and next the petroleum nozzle gently, the very first spray of oil coming on the flaming waste immediately ignites without any explosion whatever; after which the quantity of fuel can be increased at pleasure. By looking at the top of the chimney, the supply of petroleum can be regulated by observing the smoke; the general rule is to allow a transparent light smoke to escape, thus showing that neither too much air is being admitted nor too little. The combustion is quite under the control of the driver, and the regulation can be so effected as to prevent smoke altogether.

While running, it is indispensable that the driver and fireman should act together, the latter having at his side of the engine the four handles for regulating the fire; namely the steam wheel and the petroleum wheel for the spray injector, and the two ashpan-door handles in which there are notches for regulating the air admission. Each alteration in the position of the reversing lever or screw, as well as in the degree of opening of the steam regulator or the blast pipe,* requires a corresponding alteration of the fire. Generally the driver passes the word when he intends shutting off steam, so that the alteration in the firing can be effected before the steam is actually shut off; and in this way the regulation of the fire and that of the steam are virtually done together. All this care is necessary to prevent smoke, which is nothing less than a waste of fuel.

When, for instance, the train arrives at the top of a bank, which it has to go down with the brakes on, exactly at the moment of the driver shutting off the steam and shifting the reversing lever into full forward gear, the petroleum and steam are shut off from the spray-injector, the ashpan doors are closed, and if the incline be a long one, the revolving iron damper over the chimney top is moved into position, closing the chimney, though not hermetically. The accumulated heat is thereby retained in the fire-box; and the steam even rises in pressure, from the action of the accumulated heat alone. As soon as the train reaches the bottom of the incline and steam is again required, the first thing done is to uncover the chimney-top; then the steam is turned on to the spray injector, and next a small quantity of petroleum is admitted, but without opening the ashpan doors, a small fire being rendered possible by the entrance of air around the spray-injector as well as by possible leakage past the ashpan doors. The spray immediately on coming in contact with the hot chamber ignites without any audible explosion; and the ashpan doors are finally opened, when considerable power is required, or when the air otherwise admitted is not sufficient to support complete combustion.

On the spindle above the foot-plate, which regulates the supply of petroleum, is cut a double-threaded screw, having a brass nut and

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* In all the locomotives on the Grazi and Tsaritsin Railway the blast orifice is variable, as is the case on nearly all Russian railways. With the use of petroleum as fuel it is now possible to have a fixed blast-orifice of large area, thus offering less resistance.

pointer D, Figs. 6 and 8, Plate 54. This pointer traverses a brass scale graduated from 0 to 20; so that during night-time, when it is not possible to distinguish between steam or smoke from the chimney-top, the driver regulates the petroleum by means of the scale. Besides this there is a sight-hole H in the fire-door; the door itself is always kept closed, and indeed is built up with brick and plated over, as in Figs. 4, 8, and 10, Plates 52 to 55. By looking at the fire through the sight-hole it can always be seen at night whether the fire is white or dusky; in fact with altogether inexperienced men it was found that after a few trips they could become quite expert in firing with petroleum. The better men contrive to burn less fuel than others, simply by greater care in attending to all the points essential to success.

At present one hundred locomotives are running with petroleum firing: thirteen of them are passenger engines, twenty-seven are eight-wheel coupled goods engines, and sixty are six-wheel coupled. As might be expected, several points have arisen which must be dealt with in order to ensure success. For instance, the distance ring R, Figs. 8 and 10, between the plates around the firing door, is apt to leak, in consequence of the intense heat driven against it and the absence of water circulation; it is therefore either protected by having the brick arch built up against it, or, better still, it is taken out altogether when the engines are in for repairs, and a flanged joint is substituted, similar to what is now used in the engines of the London and North Western Railway. This arrangement gives better results, and occasions no trouble whatever.

Storage of Petroleum.—The length of line now worked with petroleum is from Tsaritsin to Grazi, and also the branch line from the Volga to the Don, together making a total distance of 423 miles. There is a main iron reservoir for petroleum at each of the seven engine-sheds, namely at Tsaritsin, Archeda, Filonoff, Borisoglebsk, Burnack, Grazi, and Crootaya. Each reservoir is 66 feet internal diameter and 24 feet high, and when full holds about 2050 tons. The method of charging the reservoir, which stands a good way from the line and is situated at a convenient distance from all dwelling houses and buildings, is as follows. On a siding specially prepared for the purpose are placed ten cistern-cars full of oil, the capacity of each being about 10 tons. From each of these cars a connection is made by a flexible india-rubber pipe to one of ten stand-pipes which project 1 foot above the ground line. Parallel with the rails is laid a main pipe, with which the ten stand-pipes are all connected, thus forming one general suction main. About the middle of the length of the main, which is laid underground and covered with sawdust or other non-conducting material, is fixed a Blake steam-pump. As soon as all the ten connections are made with the cistern-cars, the pump is set to work, and in about one hour the whole of the cars are discharged into the main reservoir, the time depending of course upon the capacity of the pump. All the pipes used are of malleable iron, lap-welded and of 5 inches internal diameter, having screwed coupling muffs for making the connections.

At each engine-shed, in addition to the main storage reservoir, there is a smaller distributing tank, shown in Fig. 18, Plate 58, which is erected at a sufficient height to supply the tenders, and very much resembles the ordinary water tanks. These distributing tanks are circular, $8\frac{1}{2}$ ft. diameter outside and 6 ft. high, and of $\frac{1}{4}$ inch plates; their inside mean area is calculated exactly, and a scale graduated in inches stands in the middle of the tank; a glass with scale is used outside in summer time. Each inch in height on the scale is converted into cubic feet, and then by means of a table is converted into Russian poods, according to the specific gravity at various temperatures. As it would be superfluous to graduate the table for each separate degree of temperature, the columns in the table show the weights for every eight degrees Réaumur, which is quite sufficient:—namely from 24° to 17°, from 16° to 9°, and so on, down to − 24°: the equivalent Fahrenheit range being from 86° down to − 22°. Suppose the filling of a tender-tank draws off a height of 27 inches from the distributing tank, at a temperature of say − 20° R., these figures are shown by the table to correspond with 200·61 poods = 7245 lbs. or 3·23 tons of petroleum. This arrangement does very well in practice; both the quantity and the temperature are entered on the driver's fuel bill at the time of his taking in his supply.

Besides firing locomotives, which was the main problem on the Grazi and Tsaritsin Railway, the use of petroleum is equally economical in firing other boilers. At present a Galloway boiler having two furnaces is fired with petroleum at the Borisoglebsk shops. Drawings of the arrangement are shown in Figs. 13 to 15, Plate 56; the spray-injectors are of exactly the same dimensions as those used for the locomotives, but are without the worm and worm-wheel for regulation, a simple hand-wheel being used instead. The shop boiler at Tsaritsin also is now fitted with the same appliance, the fire-box being exactly of locomotive design. There is one case of a 10-horse pumping-engine on the banks of the Volga, where the boiler is horizontal and tubular, and is fired with petroleum under the cylindrical part. As it is there necessary to raise steam sometimes from cold water, the regenerator or fire-brick chamber is so arranged as to admit of wood firing to begin with. As soon as steam is got up to 10 or 15 lbs. pressure, the spray-injector is started to work, and no more wood firing is required. In this arrangement the air necessary for combustion is heated before coming in contact with the spray, by passing it round the outside of the regenerator, which has walls 4½ inches thick, through a narrow passage as shown, thus at the same time saving the regenerator from rapid destruction by the intense heat.

Gauging of Petroleum.—The qualities of the petroleum being very different, it is indispensable that each district engineer on the line should have a hydrometer and thermometer in his office, so as to test the specific gravity and temperature of the petroleum refuse supplied; for not only are there ten different grades of quality to deal with, but the specific gravity of each varies with its temperature, and has to be taken into account in reckoning with the drivers, who are paid a premium for saving fuel. Table I. appended shows the results of laboratory research in this direction, and is taken as a standard for guidance, especially for the petroleum refuse generally met with in commerce. The laboratory temperatures are Centigrade, but Réaumur's thermometer is the one invariably used in Russia; Fahrenheit is added in the table for convenience. The heaviest petroleum refuse has a specific gravity of 0·921, or a weight of 57·412 lbs. per cubic foot when at freezing point, thus requiring a space of 39 cubic feet to contain a ton. The lightest at a temperature of 95° Fahr. has a specific gravity of 0·889, or a weight of 55·24 lbs. per cubic foot, requiring a space of 40½ cub. ft. to contain a ton. The specific gravity of the petroleum refuse delivered in December 1883, at a temperature of 8° to 9° C. (or 46° to 48° F.) was from 0·906 to 0·905, giving a weight of 56·3 lbs. per cubic foot.

Consumption of Petroleum Refuse.—Careful trials have been made to ascertain the mean consumption during continuous trips in winter and in summer; and also to determine the economy of petroleum refuse in comparison with anthracite, bituminous coal, and wood.

In Fig. 2, Plate 51, is shown the profile of the line where the experiments were made. Beginning at Tsaritsin the line rises at the rate of 1 in 125, which is also the ruling gradient, with very frequent curves of 300 sajenes = 2100 feet radius, as shown on the plan, Fig. 1. In reality the gradients are probably even steeper than 1 in 125, and the curves of even smaller radius than 2100 feet, those figures being taken from the original plans of the line when first made. As it is almost one continuous rise for about 10 miles from Tsaritsin station, without any level portions, it is necessary on this particular section to take five cars less than on any other; so that in summer the trains on this portion consist of twenty-five cars, or 400 tons gross, exclusive of engine and tender, whereas on all other parts of the line the trains contain thirty cars or 480 tons gross. The total distance from Tsaritsin on the Volga to Archeda, where engines are changed, is 97 English miles. Fully loaded trains run up from Tsaritsin; but in the return trips generally 60 per cent. of the cars are unloaded.

In Fig. 3, Plate 51, is shown the general design of the goods locomotives used in the trials. These engines were built by Borsig of Berlin, Schneider of Creusot, and the Russian Mechanical and Mining Company of St. Petersburg. Their main dimensions and weights were about the same, as follows, all of them having six wheels coupled and 36 tons adhesive weight; as originally constructed they had ordinary fire-boxes for burning anthracite or wood.

Engine.—Cylinders $18\frac{1}{8}$ ins. diameter and 24 ins. stroke. Slide-valves, outside lap $1\frac{1}{16}$ inch, inside lap 3-32 inch, maximum travel $4\frac{9}{16}$ ins.; Stephenson link-motion. Boiler pressure 120 to 135 lbs. per sq. inch. Six wheels, all coupled, 4 ft. 3 ins. diameter on tread. Distance between centres of leading and middle wheels, 6 ft. $2\frac{3}{4}$ ins.; between middle and trailing, 4 ft. $9\frac{1}{4}$ ins.; total length of wheel-base, 11 ft. 0 in. Weight empty, on leading wheels, 11 tons; middle, $10\frac{1}{2}$ tons; trailing, $10\frac{1}{2}$ tons; total weight, 32 tons empty. Weight in running order, on leading wheels, 12 tons; middle, 12 tons; trailing, 12 tons; total weight, 36 tons in running order. Tubes, number 151; outside diameter, $2\frac{1}{8}$ ins.; length between tube-plates, 13 ft. $10\frac{1}{8}$ ins.; outside heating surface, 1166 sq. ft. Fire-box heating surface, 82 sq. ft. Total heating surface, 1248 sq. ft. Fire-grate area, 17 sq. ft. Mean boiler-pressure, $8\frac{1}{2}$ atmospheres. Tractive power $= 65$ per cent. of boiler pressure $\times \frac{(\text{cyl. diam.})^2 \times \text{stroke}}{\text{diameter of wheels}}$ $= 0\cdot65 \times 127\frac{1}{2} \times \frac{(18\cdot125)^2 \times 24}{51} = 5\cdot72$ tons. Ratio of tractive power to adhesion weight $= \frac{5\cdot72}{36\cdot00} = \frac{1}{6\cdot29}$.

Tender.—Contents; water, 312 cub. ft. or 1943 gals. or $8\frac{1}{2}$ tons; anthracite, 600 poods or 10 tons; or wood, $1\frac{1}{2}$ cub. sajene or 514 cub. ft. Weight empty, $10\cdot8$ tons; weight in running order, $29\cdot3$ tons. Six wheels.

Table II. appended shows the results of a continuous set of seventeen trips made with petroleum alone, for the purpose of arriving at a mean consumption per mile; and no doubt, had the drivers had an opportunity previous to these trials of becoming thoroughly acquainted with its use, the consumption would have been less than the mean here shown of $39\cdot15$ lbs. per train-mile. The severe frosts prevalent at the time of the trials are by no means an inconvenience for the use of petroleum; it is simply necessary to exercise more rigorous care in preventing cold air from getting into the fire-box when the steam is shut off at stations or in running down hill. It is also indispensable to warm the petroleum at such periods of severe frost.

Table III. shows the results of comparative trials made in winter with different sorts of fuel, under exactly similar conditions as to type of engine, profile of line, and load of train. Two sets of comparative trials were made, both of them in winter. The three engines used were some of those built by Schneider. In comparison with anthracite, the economy in favour of petroleum refuse was 41 per cent. in weight and 55 per cent. in cost. With bituminous coal there was a difference of 49 per cent. in favour of petroleum as to weight, and 61 per cent. as to cost. As compared with wood, petroleum was 50 per cent. cheaper. At a speed of 14 miles an hour up an incline of 1 in 125 the steam pressure was easily kept up at 8 to $8\frac{1}{2}$ atm. with a No. 9 injector feeding the boiler all the time.

Table IV. gives a continuous set of nineteen trials made in summer with petroleum alone, under ordinary conditions of traffic, showing a mean consumption of 32·08 lbs. per train-mile, including lighting up. The mean evaporation per lb. of fuel was 11·35 lbs. of water from an initial temperature of about 55° Fahr.; the theoretical evaporative power of petroleum being 16·2 lbs. of water, the useful effect was therefore $\frac{11 \cdot 35}{16 \cdot 2} = 70$ per cent.

Table V. shows comparative tests made in summer with petroleum refuse versus bituminous coal and anthracite. As compared with bituminous coal, petroleum refuse shows an advantage of 56 per cent. in weight and 66 per cent. in cost; and in comparison with anthracite its economy is 52 per cent. in weight and 63 per cent. in cost. The mean speed in summer is 15 miles an hour.

Tables VI. and VII. show the monthly averages during the entire year 1883 of consumption and cost of fuel per train-mile in locomotives of the different classes, working main-line goods, mixed, and passenger trains. Table VI. is drawn out in the form of a diagram in Fig. 19, Plate 58, where the full lines represent coal consumption and the dotted lines petroleum; the pair of lines B B are from engines with six wheels coupled, working goods trains; and the pair D D from engines with four wheels coupled, working passenger trains. These two pairs of lines show at a glance the difference in favour of petroleum. The mean result of the pair B B for the whole year is a coal consumption per train-mile of 69·80 lbs. as compared with 43·19 lbs. of petroleum, at a cost of 10·212 pence for coal and 5·495 pence for petroleum; being an advantage of 38 per cent. in weight and 46 per cent. in cost of petroleum refuse. From the pair of lines D D the mean result per train-mile is 39·38 lbs. of coal against 29·62 lbs. of petroleum, at a cost of 5·672 pence for coal and 3·808 pence for petroleum; being an advantage of 25 per cent. in weight and 33 per cent. in cost of petroleum refuse. The coal used is half of it bituminous and half anthracite; the latter is invariably from a top seam not very pure, and is called semi-anthracite, its evaporative power not being so high as that of the purer anthracite from the lower seams.

Table VIII. shows comparative trials with petroleum refuse and anthracite in passenger locomotives, giving an advantage of 36 per cent. to petroleum refuse in mean consumption per carriage-mile.

Table IX. shows comparative trials in goods engines with petroleum refuse, anthracite, and bituminous coal. The advantage in favour of petroleum in mean consumption per truck-mile is here 45 per cent. over anthracite and 57 per cent. over bituminous coal. In a subsequent trial an advantage of 57 per cent. over anthracite, and of 67 per cent. over bituminous coal, has been obtained in another of these same engines, having fore and aft ashpan doors, whereby the entering air was somewhat warmed prior to coming into contact with the gases in the combustion chamber; and the author considers that, with suitable arrangements for heating the air as highly as possible beforehand, the results already attained will ultimately be considerably surpassed.

In explanation of the apparently high consumption of fuel per mile, as shown by these Tables, it must be borne in mind that the line is a single one, having in many places 16 miles between stations, so that much time is lost in standing at stations, waiting to cross trains coming in the opposite direction, thus entailing a considerable extra consumption as compared with a double line. Moreover the trains are heavy, as much as 720 tons gross load being taken by the eight-wheeled locomotives up inclines which, though not so steep as many in England, are very long at a stretch. Also, owing to the vast extent of the open plains, stretching as far as the eye can reach, the line is altogether unsheltered from the wind, which during winter and spring is sometimes strong enough to blow the men off their engine, were they not protected by doors to the cab and by railings all round.

Petroleum is further employed by the writer as an anti-incrustator in his stationary and locomotive boilers, and he finds it the best he ever used; it also prevents priming, except when used in too large a quantity. About 4 lbs. of petroleum are now being used for every 100 miles run, and the boilers are washed out every 600 miles.

In Figs. 9, 10, and 12, Plates 55 and 56, is shown the newest construction of the regenerative combustion chamber as now used. This arrangement gives excellent results, and has the advantage firstly that no side-doors are required to be cut in the ashpan, the original front and back doors being utilised. Secondly the air drawn in through the front ashpan door is passed up through a thin brick channel A thoroughly heated, whereby the air itself is heated to a certain extent before coming in contact with the products of combustion. Two cast-iron boxes B B are built into the brickwork, in order to let a small quantity of flame pass through them to that part of the tube-plate immediately underneath the tubes, thus utilising the whole of the heating surface.

The spray-injector, as shown in Fig. 10, is placed in the ashpan; whereas in the earlier arrangements it was fixed to the fire-box, and a connection was made by a hollow stay through the water space, Figs. 8 and 17. But on the eight-wheel coupled locomotives built by Kessler of Wurtemberg the ashpans are made very deep, thus admitting of the spray-injector being applied as here shown, which is more convenient and costs less than the arrangement with shallow ashpans.

From what the author has already observed with the eight-wheeled engines that he has altered for burning petroleum, he is satisfied the results are even better than with the six-wheeled locomotives having larger diameter of wheels. This he attributes firstly to the larger extent of heating surface in proportion to tractive power in the eight-wheeled engines; and secondly to the greater frequency of the blast-beats with the smaller wheels.

Up to the present time the author has altered one hundred locomotives to burn petroleum; and from his own personal observations made on the foot-plate with considerable frost he is satisfied that no other fuel can compare with petroleum either for locomotives or for other purposes. In illustration of its safety in case of accident, a photograph is exhibited of an accident that occurred on the author's line on 30th December 1883, when a locomotive fired with petroleum ran down the side of an embankment, taking the train after it; no explosion or conflagration of any kind took place under such trying circumstances, thus affording satisfactory proof of the safety of the petroleum refuse in this mode of firing. The great facility for regulating and stopping the petroleum fire, combined with its cleanliness, is a great advantage for the regular working of the trains; and during the last fourteen years the author has never had more regular time kept, or greater freedom from stoppages and delays, than he now has with petroleum firing. This he has no doubt will have a great deal to do with lessening boiler and engine expenses in repairs and cleaning.

Another point of importance for countries where there are extensive steppes or prairies is that, as there are no sparks to fly from the chimneys and no clinkers to drop from the ashpans of the locomotives fired with petroleum, there are no prairie or steppe fires, such as are caused every summer by coal-burning locomotives. Moreover in Russia there are no roofing slates, but nearly all the engine sheds are roofed with Siberian sheet-iron, which is also used for sheathing the ceilings; this material does not last long when exposed to the sulphur evolved in coal-burning; but from petroleum fuel no trace of sulphur is found.

Although it is scarcely possible that petroleum firing will ever be of use for locomotives on the ordinary railways of coal-bearing England, yet the author is convinced that, even in such a country, its employment would be an enormous boon on underground lines.

TABLE I.—*Petroleum Refuse.*

Specific Gravity and Weight per cubic foot, at various temperatures.

Water = 1·0000 specific gravity, at 17½° Cent. = 63½° Fahr.

Temperature.			Specific Gravity.	Weight in lbs. per cubic foot.
Centigrade.	Réaumur.	Fahrenheit.		
0	0·0	32·0	0·9110	56·61
1	0·8	33·8	0·9103	56·55
2	1·6	35·6	0·9097	56·50
3	2·4	37·4	0·9091	
4	3·2	39·2	0·9085	56·42
5	4·0	41·0	0·9078	56·36
6	4·8	42·8	0·9072	
7	5·6	44·6	0·9066	56·30
8	6·4	46·4	0·9060	
9	7·2	48·2	0·9053	56·20
10	8·0	50·0	0·9047	56·14
11	8·8	51·8	0·9041	
12	9·6	53·6	0·9034	56·11
13	10·4	55·4	0·9028	56·05
14	11·2	57·2	0·9022	
15	12·0	59·0	0·9016	55·99
16	12·8	60·8	0·9009	55·92
17	13·6	62·6	0·9003	
18	14·4	64·4	0·8997	55·84
19	15·2	66·2	0·8991	
20	16·0	68·0	0·8984	55·81
21	16·8	69·8	0·8978	55·74
22	17·6	71·6	0·8972	
23	18·4	73·4	0·8965	55·68
24	19·2	75·2	0·8959	55·62
25	20·0	77·0	0·8953	
26	20·8	78·8	0·8947	55·55
27	21·6	80·6	0·8940	
28	22·4	82·4	0·8934	55·48
29	23·2	84·2	0·8928	55·43
30	24·0	86·0	0·8922	
31	24·8	87·8	0·8915	55·37
32	25·6	89·6	0·8909	55·30
33	26·4	91·4	0 8903	
34	27·2	93·2	0·8896	55·24
35	28·0	95·0	0·8890	

Equivalent Russian and English Measures.

1 sajene = 7 feet. 500 sajenes = 1 verst = 0·6629 mile.

1 pound = 0·90285 lb. 40 pounds = 1 pood = 36·114 lbs. 62·0257 poods = 1 ton.

1 copeck = 0·24 penny. 100 copecks = 1 rouble = 24 pence.

TABLE II.—*Petroleum Refuse.*

Continuous Trials in Seventeen Trips on different sections of Grazi and Tsaritsin Railway, to ascertain Mean Consumption in Winter time.

Date. 1883.	Section of Line.	Locomotives.	Train.	Train alone. Number of loaded Cars.	Train alone. Gross Load.	Distance run.		Car-Miles.	Petroleum Refuse consumed, including lighting up.	Atmospheric Temperature.		Weather.
				No.	Tons.	Versts.	Miles.		Tons.	Réaum.	Fahr.	
Jan. 18	Borisoglebsk to Burnack, and back .	23	24–23	24	384	144	95	2280	1·739	−15°	−2°	Side wind.
19	Ditto, ditto. . . .	23	28–25	24·33	389·3	144	95	2303	1·854	−8 to −10	14 to 9½	Strong side wind.
21	Borisoglebsk to Filonoff	23	29	26	416	104	69	1794	1·116	−5	21	Calm.
22	Filonoff to Archeda .	23	21	23·4	374·4	118	78	1825	1·4401	−7	16	Light side wind.
23–4	Archeda to Tsaritsin, and back. . . .	23	27–32	24	384	292	193	4632	3·581	−17 to −18	−6 to −8½	Strong side wind.
Feb. 13	Archeda to Tsaritsin .	8	27	14	224	146	97	1358	1·326	−4	23	Light wind.
15	Borisoglebsk to Tsaritsin. . . .	7	27–31	22	352	368	254	5588	4·653	−6	18½	Light side wind.
23	Ditto	35	27–31	22	352	368	254	5588	4·657	−10 to −15	9½ to −2	Strong side wind.
March 8	Archeda to Tsaritsin .	8	21	14	224	146	97	1358	1·394	+2	36½	Calm.
11	Tsaritsin to Archeda, and back. . . .	14	26–31	24·43	390·9	292	193	4698	3·2205	−7	16	Side wind.
14	Archeda to Ilovla. .	40	30	21	336	58	38	798	0·5901	−11	7	Calm.
Means and Totals				21·74	347·9	2180	1463	32222	25·5707			

Mean Consumption of Petroleum Refuse = **39·15 lbs.** per train-mile, including lighting up.
Mean Cost of Petroleum Refuse, at 21*s.* per ton, = **4·4 pence** per train-mile.

TABLE III.—*Petroleum Refuse.*

Comparative Trials with Petroleum, Anthracite, Bituminous Coal, and Wood, between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, in Winter time. (*Figs.* 1 *and* 2, *Plate* 51.)

Date. 1883.	Locomotive.	Train.	Train alone. Number of loaded Cars.	Train alone. Gross Load.	Distance run.	Car-Miles.	Fuel.	Consumption, including lighting up. Total.	Consumption, including lighting up. Per Train-Mile.	Cost of Fuel per Train-Mile.	Atmospheric Temperature, and Weather.
			No.	Tons.	Miles.					Pence.	
Feb. 8	8	32–23 32–23	25	400	388	9700	Anthracite	31779 lbs.	81·90 lbs.	11·957	− 17° to − 18° Réau. equivalent to
	14	24–21 24–21	25	400	388	9700	Bituminous Coal	37557·5 lbs.	96·53 lbs.	14·093	− 6° to − 8½° Fahr.
	7	26–29	25	400	194	4850	*Petroleum Refuse*	9462 lbs.	48·77 lbs.	5·487	Strong side wind.
Mar. 6	24	32–23	25	400	194	4850	Anthracite	12639·5 lbs.	65·15 lbs.	9·512	− 5° to − 9° Réau. equivalent to
	21	24–21	25	400	194	4850	Wood, in billets	1071·8 cub. ft.	5·52 c. ft.	8·5	21° to 12° Fahr.
	23	26–27	25	400	194	4850	*Petroleum Refuse*	7223 lbs.	37·23 lbs.	4·188	Light side wind.

Prices of Fuel.—Petroleum Refuse, 21*s.* per ton. Anthracite, and Bituminous Coal, 27*s.* 3*d.* per ton.
Wood, in billets, 42*s.* per cubic sajene = 343 cubic feet; equivalent to 1·47 penny per cubic foot.

Dimensions of Locomotives.—Cylinders 18⅛ ins. diam. and 24 ins. stroke. Wheels 4 ft. 3 ins. diam. Total heating surface 1248 sq. ft. Total adhesion weight 36 tons. Boiler pressure 8 to 9 atm.

TABLE IV.—*Petroleum Refuse.*

Continuous Trials in Nineteen Trips between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, to ascertain Mean Consumption in Summer time. (*Figs.* 1 *and* 2, *Plate* 51.)

Date. 1883. June.	Locomotive.	Train.	Number of loaded Cars. From Tsaritsin to Gorodisha, 14 miles.	From Gorodisha to Archeda, 83 miles.	From Archeda to Tsaritsin, 97 miles.	Mean for total distance.	Distance run.	Petroleum Refuse consumed, including lighting up.	Mean Results, including lighting up.
			No.	No.	No.	No.	Miles.	Ton.	
8	15	38	25	30	..	29	97	1·715	**Mean Consumption** of Petroleum Refuse, **32·08 lbs.** per train-mile.
..	29	28	25	30	..	29	97	1·847	
9	15	25	..	..	30	30	97	1·219	
..	29	27	..	..	30	30	97	1·128	
..	57	30	25	30	..	29	97	1·704	
..	23	32	25	30	..	30	97	1·456	**Mean Cost** of Petroleum Refuse, at 21*s.* per ton, **3·61 pence** per train-mile.
10	15	38–25	25	30	30	29	199	2·957	
11	29	31	..	..	31	31	97	1·256	
..	23	21	..	..	30	30	97	1·149	
10	29	30	25	30	..	29	97	1·453	
11	23	12–21	25	30	..	29½	194	2·701	
12	29	26–27	25	30	30	29½	194	2·828	**Mean Evaporation,** **11·35 lbs.** of Water per lb. of Petroleum Refuse.
17	57	34	12	30	..	27½	97	1·419	
21	14	36	10	30	..	27	97	1·399	
22	14	11	..	..	30	30	97	1·138	
..	57	21	..	..	30	30	97	1·102	
Mean and Totals . . .						29·3	1848	26·471	

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TABLE V.—*Petroleum Refuse.*

Comparative Trials with Petroleum, Anthracite, and Bituminous Coal, between Archeda and Tsaritsin on Grazi and Tsaritsin Railway, in Summer time. (*Figs.* 1 *and* 2, *Plate* 51.)

Date. 1883. July.	Locomotive.	Train.	Train alone. Number of loaded Cars.	Train alone. Gross Load.	Train-Miles.	Fuel.	Consumption, including lighting up. Total.	Consumption, including lighting up. Per Train-Mile.	Cost of Fuel per Train-Mile.
			No.	Tons.			Lbs.	Lbs.	Pence.
13	37	.....	30	480	194	Bituminous Coal	14084·07	72·598	10·599
13	14	.....	30	480	194	*Petroleum Refuse*	6175·325	31·831	3·581
25	32	31–34	30	480	194	Anthracite	12784·002	65·897	9·621
25	57	27–12	30	480	194	*Petroleum Refuse*	6103·097	31·459	3·539

Prices of Fuel.—Petroleum Refuse, 21*s.* per ton. Anthracite, and Bituminous Coal, 27*s.* 3*d.* per ton.

TABLE VI.—*Consumption of Fuel per Train-Mile.*

Comparative Monthly Averages during 1883 *with Coal and Petroleum Refuse in Locomotives working main-line trains on Grazi and Tsaritsin Railway.*

See Fig. 19, Plate 58.		Fuel.	Monthly Averages of Consumption per Train-Mile.												Mean.
Locomotives.	Trains.		Jan.	Feb.	Mar.	Apl.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	
			Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Eight wheels coupled	Goods ...A	Coal*	98·06	108·96	100·79	76·27	76·27	79·00	74·91	73·55	79·00	85·81	98·06	95·34	87·17
Six wheels coupled ...	Goods ... B	Coal*	73·55	77·63	70·82	64·01	55·84	61·29	54·48	55·84	65·38	80·36	92·62	85·81	69·80
	B	*Petroleum Refuse*	**53·12**	**54·48**	**46·31**	**42·22**	**34·05**	**35·41**	**31·33**	**36·10**	**40·86**	**39·50**	**50·39**	**54·48**	**43·19**
Four wheels coupled	Mixed ...C	Coal*	51·76	76·27	43·58	34·05	36·77	35·41	42·22	49·03	51·76	40·86	49·03	58·57	47·44
Four wheels coupled	Pass. ... D	Coal*	40·86	49·03	46·31	36·77	34·05	32·69	31·33	32·69	36·77	39·50	42·22	50·39	39·38
	D	*Petroleum Refuse*	...	...	...	...	...	...	...	...	**20·43**	**31·33**	**32·69**	**34·05**	**29·62**

* Of the Coal consumed, 49 per cent. was Anthracite, and 51 per cent. was Bituminous coal. The anthracite used is from a top seam not very pure, and is called semi-anthracite.

TABLE VII.—*Cost of Fuel per Train-Mile.*

Comparative Monthly Averages during 1883 *with Coal and Petroleum Refuse in Locomotives working main-line trains on Grazi and Tsaritsin Railway.*

Locomotives.	Trains.	FUEL.	Monthly Averages of COST per Train-Mile.												MEAN.
			Jan.	Feb.	Mar.	Apl.	May.	June.	July.	Aug.	Sep.	Oct.	Nov.	Dec.	
			Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	Pence.
Eight wheels coupled	Goods	Coal *	13·495	15·635	14·346	11·226	11·319	11·704	11·186	10·925	11·552	12·471	14·600	13·930	12·699
Six wheels coupled ...	Goods ...	Coal *	10·520	11·099	9·897	9·405	8·387	9·317	8·217	8·279	9·694	11·776	13·647	12·344	10·212
		Petroleum Refuse	**7·294**	**7·602**	**6·158**	**4·973**	**4·040**	**4·163**	**3·617**	**4·170**	**4·948**	**4·771**	**6·817**	**7·356**	**5·495**
Four wheels coupled	Mixed......	Coal *	7·353	10·973	6·672	4·934	5·466	4·988	6·267	7·269	11·215	5·908	7·102	8·652	6·932
Four wheels coupled	Passenger	Coal *	6·070	7·023	6·602	5·144	4·829	4·670	4·445	4·819	5·165	5·633	6·111	7·580	5·672
		Petroleum Refuse	...	...	...	...	...	...	...	...	**2·411**	**5·611**	**4·366**	**4·634**	**3·808**

* Of the Coal consumed, 49 per cent. was Anthracite, and 51 per cent. was Bituminous coal. The anthracite used is from a top seam not very pure, and is called semi-anthracite. Mean Prices of Fuel.—Petroleum Refuse, 23*s.* 4*d.* per ton. Coal, 27*s.* per ton.

TABLE VIII.—*Petroleum Refuse.*

Comparative Trials with Petroleum and Anthracite,
between Grazi and Borisoglebsk on Grazi and Tsaritsin Railway.

Date. 1884. June.	Locomotive.	Train.	Train alone. Mean Number of Carriages.	Train alone. Gross Load.	Distance run. Train-Miles.	Distance run. Carriage-Miles.	Fuel.	Consumption, including lighting up. Total.	Per Train-Mile.	Per Carriage-Mile.	Mean per Carriage-Mile.	Weather.
			No.	Tons.				Lbs.	Lbs.	Lbs.	Lbs.	
6–7	109	4–3	15	240	264	3960	Anthracite	11560·5	43·79	2·92	3·118	Good.
8–9	109	4–3	13	208	264	3432	Anthracite	11379	43·101	3·316		
7–8	116	4–3	13	208	264	3432	*Petroleum Refuse*	6720	25·45	1·957	1·983	Good.
9–10	116	4–3	$12\frac{1}{2}$	200	264	3300	*Petroleum Refuse*	6632·5	25·124	2·01		

Dimensions of Passenger Locomotives (Borsig's).—Cylinders, $17\frac{3}{8}$ ins. diam. and 22 ins. stroke. Driving wheels, four coupled, 5 ft. 3 ins. diam. Total weight, 32 tons. Adhesion weight, 25 tons. Boiler pressure, $8\frac{1}{2}$ atm. Carriages six-wheeled, each 16 tons mean gross weight. Speed, 24 to 26 miles per hour. Maximum gradient, 1 in 125.

TABLE IX.—*Petroleum Refuse.*

Comparative Trials with Petroleum, Anthracite, and Bituminous Coal, between Borisoglebsk and Filonoff on Grazi and Tsaritsin Railway.

Date. 1884.	Locomotive.	Train.	Train alone.		Distance run.		Fuel.	Consumption, including lighting up. (*including *twice* lighting up.*)				Weather.
			Mean Number of Trucks.	Gross Load.	Train-Miles.	Truck-Miles.		Total.	Per Train-Mile.	Per Truck-Mile.	Mean per Truck-Mile.	
			No.	Tons.				Lbs.	Lbs.	Lbs.	Lbs.	
May. 20–21	147	31–28	43	688	136½	5870	Anthracite	9063	66·40	1·544	1·907	Wind favourable to train.
21–22	147	21–30	35	560	136½	4778	Anthracite	10841·5	79·43	2·27		Strong side wind.
23–24	147	31–30	38	608	136½	5187	Bituminous Coal	12638	92·60	2·436	2·436	Calm.
20–21	141	26–27	45	720	136½	6143	*Petroleum Refuse......*	6274	45·90	1·02	1·046	Strong side wind.
22–23	139	27–28	41	656	136½	5597	*Petroleum Refuse......*	5524	40·46	0·9868		Calm.
23–24	138	21–30	42	672	136½	5733	*Petroleum Refuse......*	6151	45·06	1·0728		Calm.
26	137	25–34	45	720	136½	6143	*Petroleum Refuse......*	6787	49·72	1·105		Strong side wind.
June. 26–27	143	31–28	44	704	136½	6006	*Petroleum Refuse......*	*4841	*35·46	0·806*	*0·806	Calm.

Dimensions of Goods Locomotives (Kessler's).—Cylinders, 19¾ ins. diam. and 25⅝ ins. stroke. Wheels, eight coupled, 3 ft. 11¼ ins. diam. Total heating surface, 1938 sq. ft. Total adhesion weight, 46 tons. Tractive force, 18045 lbs. = 8·056 tons. Boiler pressure, 9 atm. Trucks each 16 tons gross weight. Speed, 14 miles per hour. Maximum gradient, 1 in 125.

Discussion.

Mr. Joseph Tomlinson remarked that this paper was written almost entirely from a locomotive superintendent's point of view; and to himself therefore it was a very interesting one, as showing that nature had provided for the wants of different countries in very different ways. In the south-eastern portion of Russia, to which the paper referred, there were large quantities of petroleum, but no coal; hence the results given in the paper as to the high cost per train-mile of fuel in the shape of anthracite and other coal. But he could not help thinking that there must be some points which required clearing up in the apparent discrepancies with reference to the proportions of water and fuel. Welsh coal had a theoretical evaporative value of 14 lbs. of water per lb. of fuel, and in page 274 of the paper petroleum refuse was credited with a theoretical evaporation of 16 lbs. of water; yet it was made out that the evaporative value of petroleum refuse was from 63 to 75 per cent. higher than that of anthracite, weight for weight; and therefore he thought there must be some discrepancy that wanted clearing up. Judging from the experience of burning petroleum in lamps in England, he had no doubt good results could be obtained from it; the lamps were almost entirely free from smoke; and therefore, with proper provision for the admission of air and petroleum refuse into the fire, he did not see why a good result should not be produced, doing away with the clouds of smoke sometimes seen from engines in England. It struck him as rather extraordinary that, as the author had now had so long experience, he had not yet departed more from the ordinary form of locomotive boiler; for it would be observed that he had had to make shifts in some portions of his engines by closing up doors, which, if the engines had been originally made for burning petroleum, need not have been there at all. But possibly that was a point which would be put right hereafter. The method of arranging the supply seemed to be all that could be desired; and the method of getting rid, by opening the spray nozzle, of the small particles of dirt which would naturally be met with in fuel of that kind, was very ingenious. The author deserved their

(Mr. Joseph Tomlinson.)
thanks, he thought, for the detailed and careful information he had given.

But on the Underground Railway, with which he was himself connected, he was afraid he should get into difficulty if he were to attempt to import petroleum for the sake of getting rid of the smoke in London. London was a peculiar place; the authorities would not allow anything to be stored that was thought at all inflammable below a certain temperature; and in this respect the use of petroleum on any extensive scale would involve a very serious difficulty. Another difficulty on the Underground Railway would be one that they were already subject to in burning coal. The engines worked so long in the tunnels that a driver could not see his chimney until he got into a station. Sometimes a train might be seen on the Underground Railway coming into a station very quickly: the fireman had perhaps put a little too much fire on, and the engine was making smoke on entering the station. So long as the engines worked in short tunnels and in the open air with the South Wales coal they were now using, it was the rarest thing to see smoke coming out of the chimneys at all; indeed the chimneys of most of the engines now working on the Underground Railway were still as clean as when they first left the shop. All that was found, in the absence of smoke, was a small refuse of almost impalpable powder in the shape of unconsumed carbon, which was cleaned out of the smoke-box once a week.

Mr. William Boyd had fitted five screw-steamers trading on the Caspian Sea with arrangements for burning petroleum refuse; and in Figs. 24 to 27, Plate 60, was shown the mode in which the apparatus employed had been fitted to the ordinary marine boilers in those vessels. In the front view of the boiler, Figs. 24 and 26, the supply pipe P brought the petroleum refuse from two tanks situated at the sides of the ship, the bottom of the tanks being placed at such a height that the refuse always gravitated towards the apparatus placed in front of the boiler. The vertical pipe S supplied the steam from the boiler. The brass trunk T leading to each furnace was divided all along its length by a horizontal partition; the petroleum came in along the top channel, and the steam along the bottom, the supply of each being regulated by the cocks CC. The two orifices through which the jets of petroleum and steam issued into the furnace were inclined towards each other at an angle of about 45°, the combined jet shooting into the furnace in the manner shown in Fig. 25. This arrangement was simpler than the spray nozzle shown in Fig. 17, Plate 57, being more like the tyre-heating fire shown in Fig. 22, Plate 59. The mass of black stuff shown on the fire-bars in Fig. 25, Plate 60, was intended to represent cotton-waste or wood and shavings, saturated with oil, and set alight, in the same way as described in the paper for starting the firing in locomotives. The steam and petroleum were then admitted together gradually, until the whole spray caught fire and the flame came through the boiler tubes. From a marine engineering point of view, a peculiarity in the later of the five steamers so fired lay in the unusually great length of the boiler tubes in proportion to their diameter, the length having been materially increased as the result of experience: for whereas in the first steamer the boilers had tubes $3\frac{1}{4}$ ins. diameter and only 7 ft. long, the last one made had tubes $2\frac{3}{4}$ ins. diameter and 9 ft. long, the boiler being 12 ft. long over all. Some of the steamers had twin screws, and others had single engines, indicating from 200 to 400 HP.

It was a matter of very great regret that the author was not able to be present, because several questions might have been asked, the answers to which might have conveyed very interesting information. The price given in the paper of 21*s*. per ton for petroleum refuse was much higher than that given in the reports which the engineers sent out by himself had brought home from the Caspian Sea, where the stuff was so cheap that the steamers might almost be paid something for taking it on board. The cost of the material would of course affect very greatly the nature of any comparison with other fuel. As far as he had been able to gather, in default of any more accurate information, the consumption was something like $2\frac{1}{2}$ lbs. of petroleum refuse per indicated HP. per hour in small engines indicating 300 or 400 HP. That of course was not a very wonderful result; but the reports brought home to him showed that the stuff was very

(Mr. William Boyd.)
wastefully used, because it was thought from its being so cheap that it did not much matter whether the engines burned $2\frac{1}{2}$ lbs. or only $1\frac{1}{2}$ lb.

One point in the paper which struck him as very noticeable was that there was so large a difference between the consumption per train-mile in winter and that in summer. Under date of 8th Feb. 1883 it appeared from Table III. that the consumption of petroleum refuse was $48\frac{3}{4}$ lbs. per train-mile, and on 6th March $37\frac{1}{4}$ lbs.; while in Table IV., under date of 8th to 22nd June, being the middle of summer, there was a mean consumption of 32 lbs. per train-mile, which corresponded very closely with the consumption shown in Table V. for July. So that the consumption was increased something like 50 per cent. in the winter time, which he supposed was only what might be expected; but this point was one that it might be of considerable interest to hear something more about.

Reference had been made in the paper to the rapidity of raising steam, and also to the high temperature obtained with petroleum firing. Information in his own possession showed that steam could be raised very rapidly indeed; but of course in a marine boiler that was rather a dangerous thing to do very often. He had heard of an instance of steam being got up in rather less than an hour, the boiler containing 1800 square feet of heating surface; but he did not think such a thing should be attempted often. With the ordinary working of the marine boilers which he had described, fired with petroleum, he had not heard of any trouble, notwithstanding their long tubes of unusually small diameter; and he believed the steamers were still working satisfactorily.

Mr. G. B. Rennie considered the present paper was full of interest to the Institution, although the plans adopted for burning liquid fuel did not seem to himself to vary very much from what had been tried many years previously. About fourteen or fifteen years ago his own firm had tried it in a small boiler with an apparatus very similar to that described by Mr. Boyd, but somewhat more simple in construction. They then tried it for a month in their own shop boiler, firing for a month with coal and a month with petroleum; and at the end of the experiment they certainly found that at the price they then paid for the petroleum there was an economy, the petroleum not costing so much for the month's firing as the coal did; but after a little time they found that the petroleum increased so much in value that they did not continue to use it. In the south east of Russia, at Baku on the Caspian Sea, in the valleys of the rivers Euphrates and Tigris, and at other places in that part of the world, there was an enormous quantity of petroleum fuel to be got for merely the cost of pumping it. Shortly after the time of their own experiments, his firm were supplying some engines for vessels navigating the Tigris and the Euphrates, and it was thought advisable that the ordinary marine boilers in these vessels, working at about 30 lbs. steam pressure and having their furnaces fitted with fire-bars in the usual way, should also be furnished with spray injectors for burning petroleum. The two boilers in each vessel were usually worked one with petroleum and the other with coal, because it was found there was occasionally a difficulty in getting the petroleum sufficiently pure, and the spray injectors then got clogged up. Notwithstanding the petroleum being strained by passing through felt and other sieves, there was always some dirt coming through in it, and the pipes used to get choked up, and the firing had to be stopped in order to clear them. Nevertheless the use of petroleum was continued for some time; and the economy in weight, when firing only one boiler with petroleum and the other with coal, amounted to 20 per cent., which would of course have been 40 per cent. if both boilers had been fired with petroleum. The economy in cost was considerable with this saving in weight, because the oil was cheap and the coal dear. Eventually however the use of petroleum was abandoned, because a difficulty was found in getting it sufficiently pure; the Arabs who sold it loaded it with all sorts of rubbish. He was glad to say that Mr. Tartt, the engineer superintendent of those steamers, was present, who was more familiar with the details of the working, and would be able to give them the results of his practical experience.

Mr. WILLIAM TARTT, having recently returned from Baghdad, narrated the trials he had conducted with petroleum in Arabia. In 1869, new boilers having to be supplied to the Euphrates and Tigris Steam Navigation Company's vessel "City of London," it was thought advisable, as petroleum was plentiful in Arabia, to have them fitted up for trying its practicability. They were accordingly fitted up by Messrs. J. and G. Rennie to their own design, and sent out to Baghdad. The supply tank for petroleum was fixed on the upper deck of the vessel, and the spray pipe with its internal steam blow-pipe was passed through a plate fixed over the top of the furnace doors, the rounded top of the doors being cut off for that purpose. Petroleum was collected at three different parts of Arabia: at Hit, on the river Euphrates; at Ker-kook, some distance from the banks of the Tigris; and at Men-dil-ey, on the river Dey-el-ah. At the time of the trial petroleum could be had at Baghdad in small quantities only, and that mostly dirty. He collected it as he could, in order to make a trial; and was fortunate enough to procure it fairly good at first, and had then little or no trouble in getting it to burn. But after having been supplied once or twice by the same merchant, it was sure to be mixed with dirt, and could only be worked with great difficulty, owing to the spray pipe continually choking up. He would then change his merchant, but with the same results. It was always passed through strainers; but these would not arrest the dirt which had been mixed with it in order to make it weigh heavy. Hair and such like matter was also collected from it. One of the firemen, seeing the trouble that was experienced in getting the article pure, asked to be allowed to go to Ker-kook, his native place, in order to collect some. After some consideration he was allowed to go, and was empowered to purchase what skins he might require, and when full to send them to the bank of the river as best he could; there was no ordinary conveyance to take them. When the skins were collected on the bank of the river, a raft was made of inflated skins, with reeds in bunches secured to them; and the petroleum skins were placed on the top, and so brought down the river to Baghdad. This supply was found on trial to be very good; but it was very expensive, entailing the purchase of skins, cost of carriage, &c., and black mail to be given to the various sheiks: besides which the Turkish authorities, after knowing what was its purpose, came down heavily for customs' dues, in order to crush it out of use. However the supplies received from Ker-kook and Men-dil-ey proved to his satisfaction that petroleum could be used as fuel, and that the cost and uncertainty of the necessary supply formed the only difficulty to be overcome.

The first trial was made on 30th January 1870. There were on board 3820 okes = 4·775 tons of petroleum (800 okes = 1 ton), and on that occasion both boilers were worked with it. Steam was first raised in the usual manner; then the fires were drawn, and bricks laid on the bars, as close as possible on the back part, and covered over with ashes. On the front part of the bars the bricks were not laid so close, in order that air might pass through them; and the doors of the furnaces were also full of holes. A fire was laid on the bricks about the middle of the furnace length, where the petroleum could best be blown upon it. First the chimney blast was turned on from the main steam-pipe, when the fire soon brightened up. The steam blow-pipe was then opened, and the petroleum turned on in such a way as appeared best, so that a bright flame could be seen. Very black smoke was emitted from the funnel, and a strong smell of petroleum was to be traced behind. The consumption for six hours was 1·100 ton, or 411 lbs. per hour. A trial was then made with coal for six hours, and the result was a consumption of 1·825 ton, or 681 lbs. per hour.

On 3rd March 1870 he took on board 3694 okes = 4·617 tons of petroleum. Steam was raised as usual in both boilers; but the fires were drawn from under the port boiler only, as the starboard boiler was to be fired with coal, and the port boiler with the liquid fuel. Previously to lighting the fires under the port boiler, he had had a second bridge of bricks built in each furnace a foot in advance of the usual fire-bridge, and carried up to the crown of the furnace, holes being left between all the bricks for the flame to pass through. After the fires were drawn, the bars were covered with bricks as formerly, and the fire laid on again. Bricks were then thrown in roughly at the back of the fire; and the chimney blast, the steam

Mr. William Tartt.)

blow-pipe, and the petroleum feed were turned on, as in the former trial. At starting, and until the bricks became red-hot, there was both smoke and smell, but not quite so bad as in the first trial. When the bricks got red-hot, a beautiful white flame was the result, and steam was kept up with ease to the required pressure of 25 lbs. This trial he considered very satisfactory. The 4·617 tons of petroleum were consumed under the one boiler in 35½ hours, or at the rate of 291 lbs. per hour. The starboard boiler fired with coal needed only very easy firing, as the petroleum appeared to be doing the greater amount of work; it consumed 4·050 tons of coal, or at the rate of 255 lbs. per hour. The total consumption of coal and petroleum together amounted to 546 lbs. per hour, as against 681 lbs. of coal per hour in the trial in January.

On 9th April 1870 he took on board 3315 okes = 4·144 tons of petroleum; but it was so bad that it was with difficulty it could be used at all, and no account was therefore kept of it. He then changed to another merchant, who supplied 943 okes = 1·179 ton as a trial: this burnt well, and he ordered a supply. On 14th May he was supplied with 3214 okes = 4·018 tons, which proved as bad as any he had had, or worse; and 496 okes were returned on the merchant's hands. It was after these trials that the fireman was sent to Ker-kook, as previously mentioned; and although the results obtained from the supply thus procured were very good, he regretted that the expense had proved so great that the further use of petroleum had been discontinued.

Mr. T. R. Crampton considered this paper a very valuable one, not only from the important results obtained, but also because it brought so clearly before the Institution the fact that petroleum could be so successfully used under favourable circumstances. Its success of course depended simply upon its relative cost and heating value. Many years ago petroleum oil had been credited with a theoretical evaporative value of about 18 lbs. of water per lb. of oil, as against 14 lbs. for coal; consequently to make them equally useful economically there must be that proportion of price between them. Some fourteen or fifteen years ago he had had occasion to discuss the question with the government authorities who were at that time making experiments on the use of liquid fuel; and he had told them it was useless to attempt to go on at the price. It would pay very well just then; but all the supply that could be got was no more than could be brought by one large steamer, and therefore, as soon as ever any considerable quantity was wanted, up would go the price: so that it would be useless to carry on the experiments under those circumstances. The way in which the petroleum refuse was being burnt in the locomotives described in the paper seemed to him a capital one, and he thought it could not very well be better; but in all these cases he thought the air also should be absolutely injected with the steam and oil, and mixed with them in the exact proportion required for perfect combustion. According to the evidence of what was being done, there were only 12¼ lbs. of water actually evaporated per lb. of petroleum, although its theoretical evaporative power was 16 lbs. Certainly with a material like that, which was easily mixed with air, and in this respect was not like coal which was difficult so to mix, a duty of at least 80 or 85 per cent. ought to be got, simply by properly mixing it; and there ought not to be a doubt about complete absence of smoke. It had been remarked by previous speakers that sometimes a great deal of smoke had been made in burning petroleum; but there was no necessity for this if the air was properly mixed with it. With regard to what Mr. Tartt had maintained about the firing of his boilers, there would have been no necessity to light up the fire beforehand if he had simply put the ignited coal on the bars and had blown the air upon it alone; then without having any open fire-bars the fire could be got up very well. He had done this himself many times under those conditions, and there was no difficulty in it.

He should like to know what was the temperature in the smoke-box when burning petroleum, as it could not be known whether the boilers were adapted for the purpose unless the temperature going away from the ends of the tubes into the chimney was known. In the locomotive boiler shown in the drawings the temperature he considered ought to be very much lower in the smoke-box than when burning coal; but nothing was stated about this. His own

(Mr. T. R. Crampton.)

impression was that a great deal of heat must be lost, and that perhaps as much as 700° or 800° F. went up the chimney; if so, that would account for only $12\frac{1}{4}$ lbs. of water being evaporated per lb. of petroleum. From his own experience he was perfectly satisfied that petroleum could be used quite practically and quite economically, provided the price was not too high.

Mr. F. C. Marshall, having fitted the boilers of one vessel for the use of petroleum fuel, thought it might be of interest that he should confirm Mr. Boyd's remarks, and show how some points had been dealt with by himself. The mode of supplying the petroleum was very much after the fashion shown by Mr. Boyd in Figs. 24 to 27, Plate 60, only that it was done through two separate pipes pointing towards each other. As already remarked, it was found necessary that the boilers should be made of greater length than usual, on account of the great length of flame that was obtained from the petroleum oil. In his own case the furnaces and tubes were made longer than those spoken of by Mr. Boyd. The tubes were $2\frac{1}{2}$ ins. diameter and 10 ft. long, and even then the flame was found to come out of their further ends, the heat not having been fully absorbed. This he attributed to some extent to the want of air, to which Mr. Crampton had so properly called attention: in fact in a large proportion of furnace operations he thought the question of the supply of air was one to which sufficient attention was not given, and especially in the use of petroleum oil. It would undoubtedly be a very great advantage that the air should be driven in along with the fuel and with the amount of steam necessary for causing and distributing the spray. Certainly in the case of the boilers he had had to do with, the want of air had been very evident. The volumes of black smoke emitted from the chimney were a great cause of complaint against vessels using petroleum oil on the Volga; and it required the greatest care on the part of the stokers and engineers to keep down this nuisance. As to the efficiency of the fuel, he was afraid sea-going engineers still needed a large amount of education before being sent out, to enable them to make useful reports; he only wished all reports were as complete as that which had just been laid before the meeting by Mr. Tartt. In the case of the vessel he had himself been concerned with, the engineer on his return could give very little idea of the relative value of the oil and coal: all he could say was that he could keep steam very much better by using oil than by using wood or coal. One very great advantage in the use of petroleum in steaming was that there was no opening and shutting of fire-doors, and consequently a much greater uniformity of temperature in the furnaces could be preserved.

With reference to the raising of steam very quickly, Mr. Boyd had said he thought it would be a dangerous thing to resort to this too often. That appeared to himself to be a question to which the attention of mechanical engineers should be more directed. It was very unfortunate that up to the present time no boiler had been devised in which the circulation of the water was thoroughly effected during the process of raising steam. There was no reason why this should be so. If the necessary heat could be developed from the fuel in a shorter time, as it certainly could be, why should two or three hours be required for getting up steam? In any ordinary marine boiler one hour ought to be ample. In a locomotive boiler it was found that steam could be got up in half an hour; and he saw no reason why any advantages possessed by the locomotive boiler could not be introduced into that for marine purposes.

There could be no question as to the advantage of petroleum fuel, and the importance of the present paper. For he believed the time would soon arrive when English vessels going to the Black Sea and Mediterranean would find it to their advantage, instead of carrying their coals from Cardiff or Newcastle, to take liquid fuel at some of the ports in the Black Sea or the Sea of Azof. It was quite certain that this would come about in time; and therefore contributions of the nature of the present paper to the Institution Proceedings were very valuable, and were worthy of very careful study. The question of the economy of any fuel, as Mr. Crampton had said, was very largely regulated by its price at the place, and by the efficiency with which it could be utilised on board ship. The temperature of the smoke-box also was a question which he thought had received too little attention; much valuable fuel was allowed to

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(Mr. F. C. Marshall.)
go up the chimney. With only a natural draught it was of course essential that the temperature of the chimney should be high, inasmuch as upon it depended the quantity of air admitted to the furnace. For his own part he felt deeply interested in anything that could be devised for the purpose of dispensing with the chimney altogether as a draught-producing agent, and in any means for keeping the temperature of the gases in the smoke-box as low as possible; the extreme limit of theoretical perfection would of course be that they should not be much hotter than the temperature of the steam in the boiler. Personally he felt very much indebted to the author of the present paper; and he believed the members generally felt so too.

Mr. Emerson Bainbridge observed that the paper appeared to hold out no hope as to the use of petroleum refuse in this country, except for the purpose of underground work; and having himself had a good deal of experience of underground haulage in collieries, he was of opinion that neither from the point of view of economy nor from that of convenience or of safety would petroleum for such a purpose be of the least use in this country. There were only two systems of mechanical underground haulage at present in use: one was by locomotives, worked by compressed air; and the other was by ropes, employed in about a dozen different ways. The true comparison between petroleum and coal for underground work would of course be by considering both applied to locomotives. As the working of coal and other minerals went on year by year, they had to be hauled over much greater distances underground than was the case ten or twenty years ago; and at the present time it was no uncommon thing to have to carry coals underground two or three miles. For these distances there was little likelihood of locomotives ever contending with ropes, because air pipes would have to be laid for conveying the compressed air underground to the far distant point where the coal was got; and moreover the obstacles to be overcome were greater, owing to the work having to be done, as it were, in the dark. Mining engineers much preferred to concentrate at one point all their chief risk of an engine breaking down, rather than to run that risk at a thousand different points along the road.

As regarded the cost of petroleum, the price given in the paper was 21*s.* a ton; and though he did not know at what price such petroleum could be delivered in this country, he believed the present price of the cheapest form of petroleum was about four times as much. Assuming the 21*s.* to be increased only three times, say to 63*s.* delivered at works, this would have to be compared with the ordinary price of coal used for colliery boilers, which was about 3*s.* 6*d.* a ton; and assuming that the coal was utilised to the extent of about 50 per cent. in a compressed-air locomotive, this would give about 7*s.* per ton for coal when applied in producing compressed air for underground locomotive purposes, in comparison with 63*s.* per ton for petroleum: so that the price of petroleum for underground purposes in this country would come to no less than nine times as much as the price of coal. If these figures were correct, they would certainly preclude the use of petroleum.

Mr. Jeremiah Head considered that brickwork inside the furnaces fired with petroleum was absolutely essential. In the case of the locomotive fire-box shown in the drawings, a considerable extent of the heating surface was apparently obliterated by it; yet the author had been driven to have that elaborate brickwork inside the furnace to keep the combustion steady and continuous. Until Mr. Tartt spoke, he had been wondering why, seeing it was found necessary in the locomotive, yet in the marine fire-box shown in Mr. Boyd's drawing, Fig. 25, Plate 60, nothing of the kind was to be seen except the small bridge at the back end of the fire-grate. Mr. Tartt however had explained that his experience had also driven him to put brickwork in for no other reason than to make a sort of reservoir or fly-wheel for heat: and in fact it would be as reasonable to expect that oil would burn steadily and continuously without a wick, as that combustion could be steadily maintained in furnaces of that sort without something like a regulator or accumulator of the heat. All that he had heard seemed to drive him to the conclusion that it was of very great importance to heat both the petroleum and the air beforehand. In the tender where the fuel was stored, it seemed to be necessary, according to the

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Mr. Jeremiah Head.)

temperature of the atmosphere at the time, to heat the petroleum with steam, partly in order to get rid of the water mixed with it, and partly that it might be so far heated by the time it came to be burned. As far as he had been able to follow the paper, it did not seem to be very clearly explained how the air was actually got to the fuel. There was elaborate provision for introducing the steam; but it was not mentioned whether that steam brought in any air with it by acting as an injector. In passing through the furnace he supposed that for the most part, if not entirely, the steam went right through to the smoke-box as steam, that is to say, without undergoing any decomposition. Perhaps the President would tell them how far that was the case. If it were so, the sufficiency of the supply of air had not been very clearly pointed out. It had been shown that the great trouble was smoke, and that in the marine boilers there was a tendency to emit immense volumes of smoke: proving the insufficiency of air, and consequently the imperfection of combustion. Therefore it seemed to him that what was really wanted was such an improvement as should ensure that a full and sufficient quantity of air should be introduced, and also that by means of the brickwork in the furnace the temperature should be evenly maintained, so that it should not fluctuate too much; and the air as well as the fuel should be heated as highly as possible beforehand, so that, when they got to the point where combustion was desired, that combustion might take place instantly and completely.

Mr. PERRY F. NURSEY said that, so far as he had observed during the discussion, the question of the adoption of petroleum in England appeared to be a matter of opinion as regarded economy; but he happened to be acquainted with one little matter of fact which it might be of interest to mention in confirmation of that opinion. In 1868 he had a run on the Thames, from London Bridge to below Gravesend, in the "Retriever" of 500 tons burthen and having engines of 90 H.P. nominal, which was intended to work on the Scotch coast and was fitted up with an apparatus for burning petroleum. The petroleum furnace was that of Mr. Edward Dorsett, by whose system the petroleum was first vaporised in a generator resembling a small vertical boiler, and the vapour was then burned in jets in the furnace. The coal-burning furnace of the vessel was altered for the liquid fuel by the removal of the fire-bars, and by the filling up of the ashpit with perforated fire-bricks, upon which the coil of jets rested. During the run the steam was kept up, and everything was perfectly satisfactory; and it was intended to continue running the boat with petroleum, which was to be supplied to her from some petroleum refining works at Deptford. At the time the boat was fitted, there was no objection on the part of those works to contract for a forward supply; but afterwards, when the plan was found to be a success and application was made to the same works to enter into a forward contract, they would not do so except at prohibitive prices: so that, as far as working in England went, that scheme fell to the ground; and he believed it was for the same reason that Richardson's petroleum furnace fell through, which had been worked for many years experimentally at Woolwich Arsenal.

On page 288 of the paper reference had been made to the fact of petroleum acting as an anti-incrustator and as a preventive of priming; and he had himself had some experience of it in both those capacities. Some years ago Mr. William Major, an English engineer in the marine service of the Danish government, had introduced the use of petroleum for preventing priming; and had applied it to several boilers with great success, particularly to the Danish royal steam-yacht, by injecting small quantities of petroleum with the feed-water. The matter had been taken up in England by himself in 1878; and amongst others two boats running on the Tyne were fitted with it, and one belonging to the Brighton Railway, running between Newhaven and Dieppe and called the "Ida." She was fitted with boilers of 50 H.P., in which there was some defect that caused them to prime so badly that they were about to be taken out, when Mr. Stroudley heard of this preventive and applied it to them. It consisted simply of a tank containing 10 or 15 gallons of petroleum, according to the size of the boat, which was fixed in a corner of the engine-room, with a pipe leading from it to the feed-pump of the boilers. The practice was, just when starting on a

(Mr. Perry F. Nursey.)
voyage, to run half a pint of petroleum into the boilers with the feed-water; and in six hours' time, when the boat got half-way across the channel, the same quantity was again injected, which lasted for the rest of the run. The result was that the priming was stopped, and there was never any more trouble with incrustation or scale; and more than that, the engine was found to be kept thereby very efficiently lubricated: thus confirming what the author said about the good effect of petroleum as a preventive not only of incrustation but also of priming. In cases where priming had occurred with the use of petroleum, he believed it would be found that rather too much petroleum had been used at first; and it would be noticed that a caution had been given in page 288 of the paper against using it in too large a quantity.

Mr. J. Phillips Bedson mentioned that some years ago, when petroleum was very cheap in the Manchester district, it was used there for firing hand-fired boilers in a manner similar to that described in the paper. His own firm being at that time manufacturers of charcoal iron, and having a large quantity of charcoal dust that they could not dispose of at any price, bought petroleum and mixed it with the charcoal dust so as to saturate it, and then burned the mixture on the boiler grate. But as previous speakers had already stated, after awhile the price advanced, and the plan had to be dropped in consequence.

Mr. W. Steele Tomkins thought it would be but fair to the author to remember that the locomotive boiler shown in his drawings was not originally adapted specially for the burning of oil. It was indeed only a make-shift for experimental purposes; and there was no doubt at all that if, as seemed likely, the burning of oil rendered it sufficiently worth his while to make a special boiler, he would alter the construction of the boiler for that purpose. It appeared to himself that the boiler might be very much simplified, so as to get rid of the expensive drop-firebox, and probably make the whole boiler cylindrical or nearly so, thereby altering it altogether. No doubt the proper proportions between the fire-box surface and the tube surface had yet to be ascertained, when using that kind of fuel; and he believed the whole boiler would be altered, and he hoped simplified too. Mr. Boyd had remarked how much the rate of consumption varied in different months. That was so. In Russia the consumption of fuel in locomotives during the winter months was very largely in excess of that during the summer months, and the diagram, Fig. 19, Plate 58, showed this very clearly. He thought they were all indebted to the author for his valuable paper.

Mr. C. E. CARDEW mentioned that he had had a good deal of experience on the State Railways of India in trying petroleum, or rather American kerosene and Rangoon mineral oil, for the purpose of preventing incrustation. Throughout the whole of northern India the railways were troubled with probably worse water for their locomotives than in any other country in the world. The deposition of scale, chiefly sulphates, was so bad that on some lines the engines could run only 100 train-miles before washing out; and it was only by a good deal of ingenuity that it could be managed to screw 150 to 200 miles out of an engine before it had to go into the shed. All sorts of plans had been tried for preventing the incrustation, or rather for loosening it so that it might come away readily when washed out; and also for causing it if possible to deposit in the form of a powder or sediment in the water, rather than as a scale adhering to the tubes and the heating surface generally. Among other things petroleum had been tried. In 1879 an engineer at home from India on leave learnt that petroleum was being used for that purpose on the North British Railway, where the water was of course absolutely perfect compared with that to be dealt with in India; and on his return he suggested to government that petroleum should be tried on some of the Indian railways. It was accordingly ordered to be tried all over the country; and after giving it an extended trial, he himself had reported that it would be an excellent thing for the purpose, if only it could be prevented from causing priming, though there was nothing novel in its use. In the paper it had been spoken of as a preventive of priming; but his own experience was that it often caused extensive priming, and that when

(Mr. C. E. Cardew.)
a train got out on the road with a careless driver it was never known when he would get home again. That was particularly so when it was first used in an engine, even when put into the boiler in very small proportions indeed. It seemed also to have the effect of searching out every weak joint in the boiler, the tubes all starting to leak badly, so much so that drivers were afraid to use petroleum. After a good deal of trial it was found that by using it in very minute quantities, very frequently supplied, they could manage to make it do its work as an anti-incrustator without causing priming. A rough-and-ready rule finally arrived at was that, each time an engine came into shed to be washed out, the tank was emptied, and a boy went in with a brush and painted the whole of its inside with petroleum. That was found to be sufficient. A very small quantity of petroleum admitted into the feed-water and well mixed was sufficient for preventing to a very large extent the serious incrustation from which the engines previously suffered; or else it made the incrustation so soft that on scraping out the inside of the boiler the stuff came away which formerly would not come away. The same plan had been tried on many of the Indian railways, some of which reported well of it, and some against it; but the general consensus of opinion seemed to be that it was rather too ticklish an expedient to be used as a regular thing.

Mr. DRUITT HALPIN mentioned that, with reference to the use of petroleum as an anti-incrustator for removing and getting rid of scale, he had himself used petroleum in this country for some years with water that was quite as bad as the Punjaub water, which he knew well. In a Lancashire boiler of 6½ feet diameter and 22 feet length, the incrustation extended solid about one-third of the way up the two flues at the time when he started using petroleum; and eventually it was thereby brought down to dust, so that it could easily be got rid of. The petroleum was used in exceedingly small quantities, a quart being put into the boiler once a week, when the steam was let down on Sunday; and it was Monday before the fire was lighted again. That small quantity was sufficient for the week; it kept the boiler surfaces clear of any scale, and there had never been the slightest trouble from priming.

The PRESIDENT quite agreed with what had been said as to the inutility of discussing the matter of petroleum fuel as a question of money. Petroleum naturally varied very much in price in different countries; and the proper and philosophical way of approaching the question undoubtedly was to ascertain the amount of duty yielded, reckoned in lbs. of water evaporated per lb. of fuel consumed. Inevitably such an event as had been referred to in the course of the discussion would take place if it were ever attempted to fire all the engines in this country with petroleum instead of with coal; for according to the table given in his opening address, he found that every year 18,936,000 tons of coal were consumed for steam engines in this country: so that, if it were attempted to substitute petroleum to that extent, there would be a speedy rise in its price.

With regard to the paper itself, he thought the length to which the discussion had gone was the best proof they could possibly have of its utility. Many questions had been entered into, which he thought the Institution of Mechanical Engineers would do well to follow up with a little more care than had hitherto been given to them. No doubt owing principally to the fact that the human race had been firing boilers for at all events nearly a century, he supposed they had been led to infer that they had arrived at perfection. Now so far as his own observation was concerned, he believed they were very far from that point; and indeed as a matter of fact he feared that serious attention enough had not been given to the subject. He was induced to make these remarks in consequence of what had fallen from Mr. Marshall, who had spoken of the temperature in the smoke-box, and had pointed out what precautions ought to be taken for avoiding any very great loss from that source. That loss might arise in one or both of two ways. It might arise from allowing the products of combustion to escape at too high a temperature, by which of course a very large amount of heat—much more than most engineers would be prepared to admit—escaped into the chimney. And this loss might be further increased by not taking care as to the proper amount of air admitted into the furnace itself. If too little were admitted, the combustion would be imperfect; and he imagined, as Mr. Marshall had pointed out, that it was probably due

(The President.)

to this cause that in the marine boilers a great amount of oil had escaped to the chimney through the tubes before it was half consumed, entailing of course a very serious loss. A loss, he would not say as serious, but of considerable magnitude, might also ensue from admitting too much air, because all excess of air had to be heated, and escaped from the boiler at the same temperature as the rest of the products of combustion; and the heat lost in that way might amount to a good deal. At the same time, while he admitted the cogency of Mr. Marshall's remarks with regard to the limit of theoretical perfection, he was far from believing it would ever be possible in practice to let the products of combustion escape into the chimney at the temperature of the steam in the boiler. That was a limit which no one could hope to arrive at, if for no other reason than that the rate at which a heated body—air for example, or any gas—was able to part with its own heat to a body cooler than itself diminished very rapidly as the two approached each other in temperature. As soon as gases got cooled down to anything like 500° or 600° Fahr., the readiness with which they parted with their heat even to cold water was very much slower than was perhaps commonly supposed; and the consequence was that, in order to get any more heat out of them, the length of the boiler would have to be extended far beyond what could be practically contemplated. But there was another objection to too low a temperature in the escaping gases. Having at one time had occasion himself to heat a large quantity of water with the least possible consumption of fuel—merely heating the water, and not raising steam from it—he had constructed a boiler 10 feet square, having two ordinary furnaces placed inside large tubes. The products of combustion on leaving the two tubes passed first along the sides of the boiler, then over the top, and lastly under the bottom, the cold water entering at the bottom and the hot water rising to and escaping at the top. Owing to the very low temperature of the products of combustion in passing along finally under the bottom, the condensation of water and of sulphurous acid upon the outside of the bottom of the boiler was so great that it corroded the bottom through in a very short time. That result of course would not take place to any such extent, and might not take place at all, in the case of an ordinary steam boiler, because there the escaping gases had a temperature which prevented condensation.

In the paper he observed that the brickwork in the furnaces was spoken of as being a "regenerator," which was rather a misleading term, because the brickwork was there not a regenerator in any sense of the word; it was really a reservoir or receptacle of heat, or a fly-wheel of heat as Mr. Head had stated; and he had no doubt it was a very useful receptacle of heat, because it kept the gases in the furnace up to the temperature at which combustion took place readily. The well known regenerator of the late Sir William Siemens trapped the heat as it was escaping from the furnace, and then gave it back again to the entering air or gas. But no such thing took place in the furnace described in the paper; here the brickwork simply got heated up to the temperature of the fire, and was retained at about that temperature, and there was no return of the heat whatever, except to the extent of equalising the temperature under the fluctuations of the firing.

It appeared from the paper that the actual heat obtained from the petroleum was not equal to its calorific power; but he did not find that any attempt had been made to point out how the deficiency had arisen. In the first place there was no doubt that a considerable amount of heat was consumed in the spray injector; but no account had apparently been taken of the steam used in the jet. Then, in addition, there was the possibility—he did not say the probability—that a large proportion of the steam in the jet might become decomposed. Now it was well known that the amount of heat absorbed in the decomposition of water, or of any other compound, was precisely equal to the heat given out by it when its elements combined. In other words, taking the calories or units of heat according to the centigrade scale, which was more convenient than the English, there were 34,000 units of heat given out by every unit of hydrogen burnt; and consequently for every unit of hydrogen separated from its oxygen in water there was an absorption of 34,000 calories or units. Of course if decomposition took place at one part of the furnace and re-union took place at another part of the furnace,

(The President.)
there would be an equilibrium established, and thus no loss would occur: there would be absorption of heat in the part of the furnace where the steam was decomposed, and evolution of heat where water was re-formed. Supposing the steam not to be decomposed, still the whole of it had to be heated up to the higher temperature of the gases passing away from the furnace; and this no doubt would be the cause of some loss. If in addition it were the fact that part or all of the steam did undergo decomposition, and without subsequent re-union, there would be absorption of the heat required to effect the decomposition. These two factors taken together would possibly account for the actual evaporative efficiency of petroleum being, as stated in the paper, only 75 per cent. of its estimated calorific power.

However that might be, he was sure the members would all agree with him that they had been listening to a very excellent paper; and he had much pleasure in asking them to join him in thanking the author for it.

Mr. URQUHART has sent the following reply to the observations made in the discussion, regretting that he was unavoidably prevented from being present at the meeting, in consequence of being summoned at that very time to St. Petersburg, in connection with petroleum-burning in locomotives and his own recent experiments on the subject.

In explanation of Mr. Tomlinson's remark that in the south-eastern portion of Russia there is no coal, the fact is that, although coal does exist there in great quantity—the centre of the anthracite basin being Grooshefka, near the town of Novo-Tcherkask on the river Don, not far from the sea of Azof—yet the distance to Grazi, the western terminus of the Grazi and Tsaritsin Railway, is no less than 420 miles. Hence, while last year the cost at the mines was 9½ copecks per pood loaded on trucks, equivalent to 11*s.* 9*d.* per ton, the mean cost on the line is 27*s.* per ton, because transport and other dues amount to as much as 15*s.* 3*d.* per ton.

As to the practical evaporation realised with semi-anthracite coal and petroleum, the figures in the paper are based upon facts confirmed by long observation. It is only at atmospheric pressure that Welsh coal has a theoretical evaporative value of 14·30 lbs. of water per lb. of coal; while at 120 lbs. per sq. in. above atmosphere, according to the best authorities, anthracite has a theoretical value of 12·2 lbs., coal 11·4 lbs., and coke 10·2 lbs. The actual evaporation obtained with coal in locomotive practice is only from 7 to 7½ lbs., thus giving about 60 per cent. of useful effect. In stating the evaporative duty of any fuel, the pressure under which the evaporation takes place must also be stated; and it has to be borne in mind that the 14 lbs. theoretical evaporative value mentioned by Mr. Tomlinson is reckoned at atmospheric pressure or 212° Fahr., and applies to best Welsh coal hand-picked. As to the calorific effect of petroleum, it is quite possible that fewer experiments have been made with petroleum than with coal; and indeed various estimates have been given of its theoretical value. Presumably the safest authority on the subject would be the able work of Sainte-Claire Deville (*Académie des Sciences*, Paris, vol. 68), where the analyses of liquid hydrocarbons from all parts of the world are to be found, including petroleum from the Caucasus. Very recent trials have given a practical evaporation of 12·25 lbs., and the author is very sanguine of this being surpassed when the air is heated. It must not be lost sight of that in firing with coal, even by skilled hands, cold air rushes in each time the fire-door is opened; and moreover each fresh shovelful of coal thrown in forms a damping heap, thus keeping the furnace comparatively cool. In this connection the author remembers hearing in 1876 at Birmingham the valuable paper on the Frisbie mechanical fire-feeder (see Proceedings 1876, page 318), which was intended to obviate chilling the furnace with the fresh fuel; and although that arrangement could not be applied to locomotives, yet more attention might advantageously be directed to it for vertical and under-fired stationary boilers.

Instead of building up the locomotive fire-door with brick and plating it over, the suggestion hinted at by Mr. Tomlinson occurred also to the author: namely, to do away with the fire-door hole

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altogether, and make the back plates of the fire-box solid throughout, just the same as the sides, with the water circulating between them, whereby fully $2\frac{1}{2}$ sq. ft. of additional heating surface would have been obtained in the fire-box. But as it is impossible to be certain that the price of refuse or crude petroleum will remain long the same as at present, the necessary provision must always be in readiness for rapidly reverting to coal firing; and moreover it is necessary to have an entrance to the interior of the fire-box for examination and repairs. Therefore the present petroleum-firing arrangements are merely the most simple, direct, and efficient means of adaptation to existing circumstances, keeping in view the possible rise in price of petroleum and reduction in cost of coal, inasmuch as the commercial side of the question has to take precedence of other considerations.

Having himself travelled many times on the Underground Railway in London, mostly in summer or autumn, the author was struck not so much with what he could observe or feel of smoke, as of suffocating sulphurous fumes, which he was told constituted to many persons a practical objection to travelling on that line. Hence his suggestion as to the possible use of petroleum on underground passenger railways—not for underground haulage in coal pits.

In England there appears to be a prevalent dread of the use of petroleum; but so far as the author is aware all experience hitherto with petroleum in England has been either with crude petroleum or with refined petroleum for lamps, and the use of petroleum refuse or residue is scarcely if at all known. Having made several experiments as to the safety of the residue, he finds it by no means the dangerous material against which there is so much prejudice under the name of petroleum. On the temperature of spontaneous combustion, and on the inflammability of the different petroleum products at various temperatures, he will be happy at a future date to offer some details to the Institution. Gaseous fuel is decidedly the most economical; and it must not be lost sight of that petroleum is simply fuel on its way—possibly half way—to a gaseous condition; hence its high efficiency.

In firing with petroleum it is not necessary to look at the top of the chimney for regulating the fire; it can be regulated by simply looking at it through a sight-hole in the fire-door, and as the heat is quite white a piece of stained glass may be put over the sight-hole in order that the eyes may not be dazzled.

In reference to Mr. Boyd's remarks, there are a variety of spray injectors in use in steamers on the Volga and the Caspian Sea, of which the most approved were published last year in *Engineering*; but so far as the author noticed no brick combustion chambers were used, the only brickwork being simply a protecting wall built up against the back plate of the combustion chamber in the marine boilers; and much smoke is consequently evolved by all the Volga steamers. It is simply matter of opinion whether the spray injector described by Mr. Boyd is in any way superior to that used by the author for locomotives and shown in Plate 57. It is well known how easily any round pieces of work are manufactured, and it will be seen from Plate 57 that the whole of the work on the spray injector there shown is done in the lathe, and is therefore exceedingly simple; round spray injectors are certainly in the author's opinion the best. But the spray injector of itself is of very secondary moment in comparison with the proper arrangement of brickwork in the combustion chamber for most efficiently heating the air; the latter is unmistakably the most important matter, and is that which has proved so very successful in the author's own experience.

As to the price given in the paper of 21*s*. per ton for petroleum refuse, this is the price at Tsaritsin—the eastern terminus of the railway—on the Volga, about 325 miles up the river from Astrachan. It is quite true that on the Caspian in 1882–83 the cost of a ton of residue was only from 2*s*. to 2*s*. 6*d*. at Baku, while at Tsaritsin it was 21*s*. The reason of the difference is that the petroleum is shipped at Baku in deep-sea steamers, and on arriving at the 9-feet harbour not far south of Astrachan it is re-pumped into river steamboats or barges having flat bottoms, thus entailing considerable expense for trans-shipment in addition to the cost of transport. In fact the inefficiency of transport is what has

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hitherto formed and still forms the great barrier to the more extended use of petroleum refuse. In the vicinity of Baku certainly no efforts were used to economise petroleum as a fuel; many works even paid for removing the refuse, and much of it has been run into the sea as quite an incumbrance. Owing to the present demand this waste has of course been now discontinued; but it was only when petroleum was used in European Russia proper that great efforts were made to devise means for most economically utilising it as a fuel.

The large difference between the consumption per train-mile in the trials on 8th February and 6th March 1883, as shown in Table III., is chiefly due to the difference of atmospheric temperature. A frost of 18° Réaumur or $40\frac{1}{2}$° Fahr. accompanied by a strong side wind is something that railway authorities in England can have little idea of. The resistance is very great, notwithstanding a reduction of 15 to 20 per cent. in the gross load. It will be seen from Table III. that the same proportionate difference took place in the coal-burning locomotives. The great difference between summer and winter consumption owing to the inclemency of the weather in winter is a matter of universal experience in Russia.

As to the high temperature obtained with petroleum firing, the author may mention that during his first trials he noticed that many nuts on the stay-bolts of the fire-box roof dropped off from the intense heat; this never took place with coal firing. On its being discovered, he made heads on the lower ends of the roof stay-bolts; but the best arrangement is Belpaire's, where the stay-bolt is screwed into both plates—the fire-box roof and the outer shell—and riveted over, thus allowing a free circulation of water over the hottest part of the fire-box. The author quite concurs in Mr. Boyd's opinion that too rapid raising of steam in a cold boiler cannot be commended, and indeed ought to be prevented.

Referring to Mr. Rennie's remarks, petroleum firing is certainly no new discovery. The author well remembers experiments being made in Glasgow in 1862 or 1863 with shale oil from Young's paraffin works, and if he is not mistaken in the same furnace was tested American petroleum.

Exactly the same fouling is mentioned by Mr. Rennie as having taken place in the spray injectors tried on the Tigris and Euphrates that is such a source of trouble on the Volga and the Caspian. All the spray injectors that the author has seen on the Volga are connected to a vertical trunnion-pipe on the right or left side of the furnace, and the whole apparatus is so arranged that it can be swung round out of gear. But this arrangement, although no doubt convenient for clearing the spray-orifices, has its dangers. Last year on one of the Volga boats one of these spray injectors got loose while working, and by the reaction of the issuing steam swung round suddenly of itself with a strong flame on, and one of the firemen was thereby burnt to death, being unable to get out of the stoke-hole quick enough. All boats in which such flat spray-orifices are used tremble very much, in consequence of the great vibration arising from all spray injectors where no brickwork is used; and it was from this vibration that the catch got loose in the fatal accident referred to. This the author considers ought to be mentioned, in order that the necessary precautions may be taken wherever petroleum may be used.

Fouling of the spray orifices takes place from other causes besides dirt in the petroleum. In all cases where the spray injector is situated inside the fire-box amongst the flame, or even very near the flame, the author has noticed that the issuing orifices get so much heated that the liquid carbonises on their surfaces, forming indeed a small deposit of coke upon them. This fouls the orifices even more than the solid particles in the liquid; but it is very completely obviated in the author's arrangement, because the spray injector is here exposed to no more heat than that due to the steam passing through the nozzles, which is not sufficient to carbonise the liquid.

Mr. Tartt's very lucid and interesting remarks confirm the author's experience with brickwork in the furnace. Even should a special boiler be prepared for petroleum firing, the author feels confident that a refractory fire-brick surface in some form or other must form an essential element in the arrangement. Supposing the combustion chamber for retaining the products of combustion were made of copper plates alone, without any fire-brick lining, not only would there be danger in exposing the metal plates direct

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to so great a flame force, but also the temperature of combustion would be much lower, and not nearly so good a result as that now attained with brickwork would be arrived at. Moreover, should a drop of petroleum fall upon a plate having a temperature due to the water in the boiler, this temperature would not be sufficient to inflame the drop; whereas the brickwork does this most efficaciously, and thus ensures complete combustion without a vestige of smoke.

It is satisfactory to learn that petroleum exists in Arabia, however undeveloped at present. In a letter from a superintending marine engineer on the river Brahmapootra in Assam, the author has been asked whether in his arrangement it is necessary to refine the petroleum, or whether it can be used in its crude state, because at their up station petroleum is to be had, though in what quantity is not known. It will thus be seen that the subject is an interesting one in many parts of the world; and no doubt petroleum will be employed as fuel in many places where it can be had in sufficient quantity and at a reasonable price. The author has made experiments with crude petroleum in his locomotives, and finds it gives a higher efficiency than the petroleum refuse, as might be expected on account of its containing more volatile matter. No inconvenience was found in using it as a regular fuel, in conjunction of course with the brick combustion chamber. The author has little doubt that crude petroleum is to a large extent mixed up with the residue supplied to him for his locomotives; but to this he has no objection so long as the supply does not contain water, which makes weight but not fuel.

The theoretical evaporative value mentioned by Mr. Crampton as having been credited to petroleum—namely 18 lbs. of water per lb. of oil, as against 14 lbs. for coal—must have been reckoned at atmospheric pressure. Among the several ways of burning petroleum, one is by letting it drop on hot bricks, or soak through a bed of hot sand; and as no steam jet is then required for producing a spray, the theoretical evaporative efficiency of the petroleum is subject to neither increase nor diminution such as might be due to the presence of steam. Although not having the means of proving it, the author is of opinion that the high-pressure steam in the jet adds much to the evaporative efficiency attained. Some estimates have even gone the length of assigning as much as 25 lbs. of water as the evaporative value of a lb. of petroleum; but the author considers it safer to keep within reasonable limits based upon its chemical components, and 16·2 lbs. of water is about the estimate thus arrived at for a pressure of 120 lbs. per square inch above atmosphere.

Of the air required to support combustion, part is drawn in by the injector itself; but when the engine is working at considerable power this is not sufficient, and the dampers must then be opened to admit more. With the dampers closed while standing at stations or under steam in the engine shed, the air drawn in by the injector itself is sufficient for the small fire required for keeping up the steam-pressure. By making some alterations in the brickwork so as to heat the air as hot as possible, and probably by also heating the petroleum refuse more than is done at present, the author hopes that the higher evaporative duty indicated by Mr. Crampton will be attained.

As to the suggestion about observing the temperature in the smoke-box when burning petroleum, the author has not as yet made any tests on this point, but will be very glad to do so at some future date.

With Mr. Marshall's very interesting remarks the author fully concurs, in regard to the possible future of petroleum as fuel on the Black Sea and Mediterranean. Batoum or Poti, on the Black Sea, would certainly be the most likely ports at which to get the supply.

The lengthening of the boiler tubes for petroleum firing he considers a step in the right direction; and this is undoubtedly one cause why he is getting a higher efficiency in the eight-wheeled locomotives than in the six-wheeled and passenger engines. It will be noticed that the relative advantages with petroleum over coal are not the same in each class of engine, the passenger engines having tubes about 11 feet long, the six-wheeled goods engines 14 feet, and the eight-wheeled over 16 feet long.

If the whole quantity of air required for complete combustion could be driven into the furnace by the action of the spray injector itself, that would certainly be a very good thing. But on the other hand there would then be no possibility of previously heating the air so

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supplied; whereas by creating a slight vacuum in the smoke-box, either by the blower or by the exhaust blasts, the air rushing into the fire-box through the various dampers can easily be made to pass through hot brick channels on its way to the fire. Two advantages are thereby gained:—firstly, that of heating the air; and secondly, the cooling action of the cold-air current entering through the passages in the brickwork tends to preserve the combustion chamber from rapid destruction. This latter advantage is so far proved in locomotive practice by the fact that the brickwork containing the air-heating passages has been found to last longer by at least 40 per cent. than the brickwork not containing passages for heating the air.

Having already mentioned that it was not his object in the paper to suggest any possibility of applying petroleum firing to underground engines in coal pits, the author will only add, with reference to the remarks of Mr. Bainbridge, that in his own opinion compressed air is the only safe and ready means of working underground engines at various points in the workings of a mine.

He is glad to observe that the brickwork in the combustion chamber is considered by Mr. Head an essential element for successfully overcoming the difficulties of practically applying petroleum as a fuel; and the expression "fly-wheel for heat" very clearly illustrates the part played by the brickwork, more especially in locomotives, where every mile run requires incessant manipulation for thoroughly working to advantage, each grade calling for its corresponding alteration. It must be admitted that within the limits of a locomotive fire-box much cannot be done in the direction of heating the air; but what is possible ought to be done. He fully concurs with Mr. Head that the heating of the liquid as well as of the air, prior to their coming into contact in the combustion chamber, is just what is wanted for attaining the maximum of efficiency. As to how the air is got to the fuel, the author of course resorts to the exhaust when running, and to the blower when making steam to begin with and when not running, whereby a vacuum of about 2 inches of water in the smoke-box is found by direct experiment to be obtained.

It may here be mentioned, with regard to the warming coil in the petroleum tank on the tender, that the arrangement described in the paper (page 278) and shown in Fig. 5, Plate 53, with an upward course for the steam through the coil, was that first employed by the author. But practice showed this to be a little defective, on account of the condensation in the coil forming a head of water, against which the steam had to force its way up; some inconvenience arose from the consequent squirting of the water out at the top of the outlet pipe, and in fact in some cases the coil got frozen up. Ultimately therefore it has been found more convenient to reverse the arrangement, giving the steam a downward course through the coil by admitting it at the top and discharging it from the bottom, so that the water drains out freely of itself, no cock being used on the outlet side.

Petroleum refuse is undoubtedly a very effective and cheap means of preventing boiler incrustation; and the author has heard from several other engineers in Russia that they have found it equally successful. He is glad to notice also that in India and elsewhere petroleum has proved so effective as an anti-incrustator. Much will depend upon the chemical qualities of the feed-water, as to how often and in what doses the petroleum ought to be injected into the boiler.

While the arrangements described in the paper are in the author's opinion and experience the simplest and most direct way of utilising liquid fuel in existing locomotives, he agrees with Mr. Tomkins that it is quite possible there may be some special way of utilising it with a higher efficiency, by making a special boiler and furnace.

As to the necessity, pointed out by the President, of admitting the exact quantity of air requisite for complete combustion, and avoiding the admission of any excess of air, this was one of the most difficult points to overcome; and notwithstanding all the care taken in supplying means of minute regulation, it was only after the drivers got convinced themselves of the necessity of very exact regulation that good results ensued. The author has found that the men get quite to understand this, as both the driver and fireman now manipulate the whole with very creditable results. For instance, when starting from a station, smoke was invariably noticed at first,

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but now, after some experience, the same men so carefully manipulate the supply of fuel and steam and air that no smoke is seen in starting from a station, and they gradually increase each of these three elements until full speed is attained.

It is quite true that the brickwork of the combustion chamber is not a regenerator in exactly the same sense as it is in a Siemens gas furnace where alternate reversals take place of the gas and air currents. But just as the preparation of the two elements, which constitute the fuel, for being ultimately burnt in the furnace is effected by the brickwork in the Siemens furnace prior to their coming in contact, so the heat absorbed by the brickwork in the locomotive fire-box tends to elevate the temperature of the gases generated from the fuel, thereby very much increasing the temperature of the fire, or regenerating the heat. Possibly the brickwork in the present case, in so far as the heating of the air is concerned, might be taken to correspond with Ponsard's gas furnace, which has a recuperator for heating the air; or with the well known heating furnace of Boetius, in which the combustion chamber is encircled by channels for heating the air not from waste gases but by the heat of the combustion chamber itself. Certainly the brickwork acts as an equaliser of fluctuating temperatures under varied circumstances, whether the locomotives be running or standing.

As to the proportion obtained out of the full calorific value of the petroleum, it can scarcely be expected, especially in a locomotive, that the same splendid results can be attained as by gaseous fuel in a Siemens regenerative furnace with reversible currents. In locomotives there must always be a considerable percentage of heat escaping up the chimney.

At some future time the author will be very glad to supplement the present paper with whatever further may seem of value and interest to the Institution on this subject.

PETROLEUM FUEL IN LOCOMOTIVES.

Grazi and Tsaritsin Railway, South Russia. *Tsaritsin to Archeda.*

Fig. 1. *Plan.*

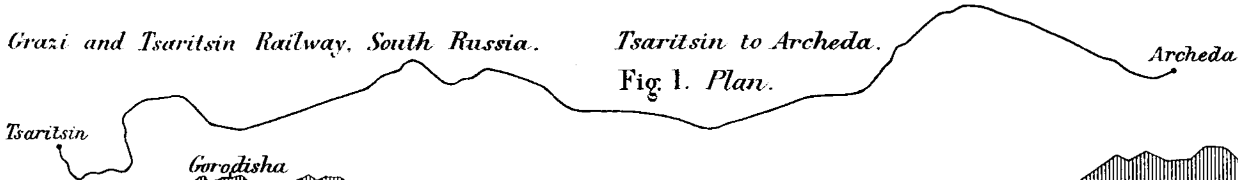


Fig. 2. *Profile.*

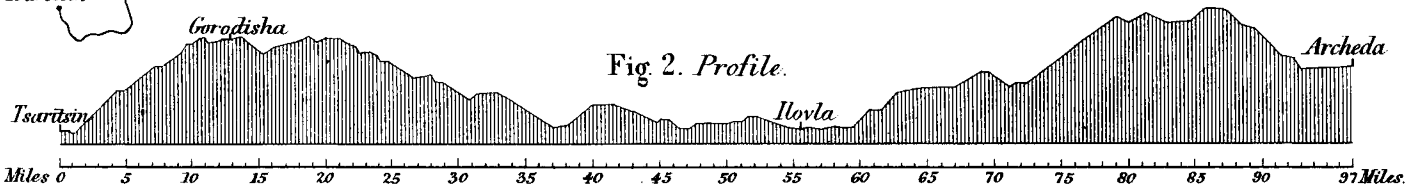
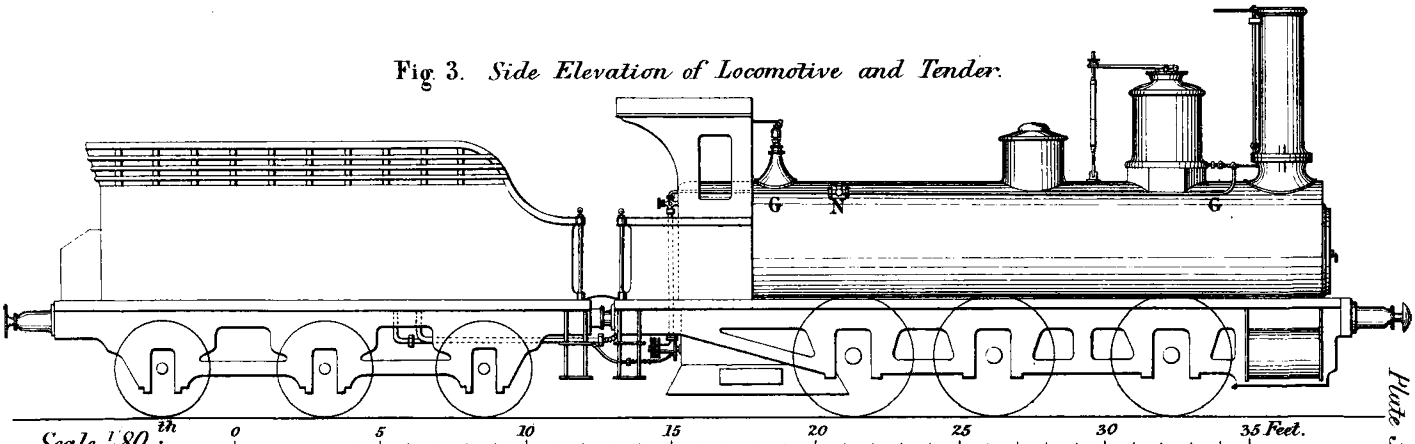


Fig. 3. *Side Elevation of Locomotive and Tender.*



Scale 1/80th

(Proceedings Inst. M.E. 1884.)

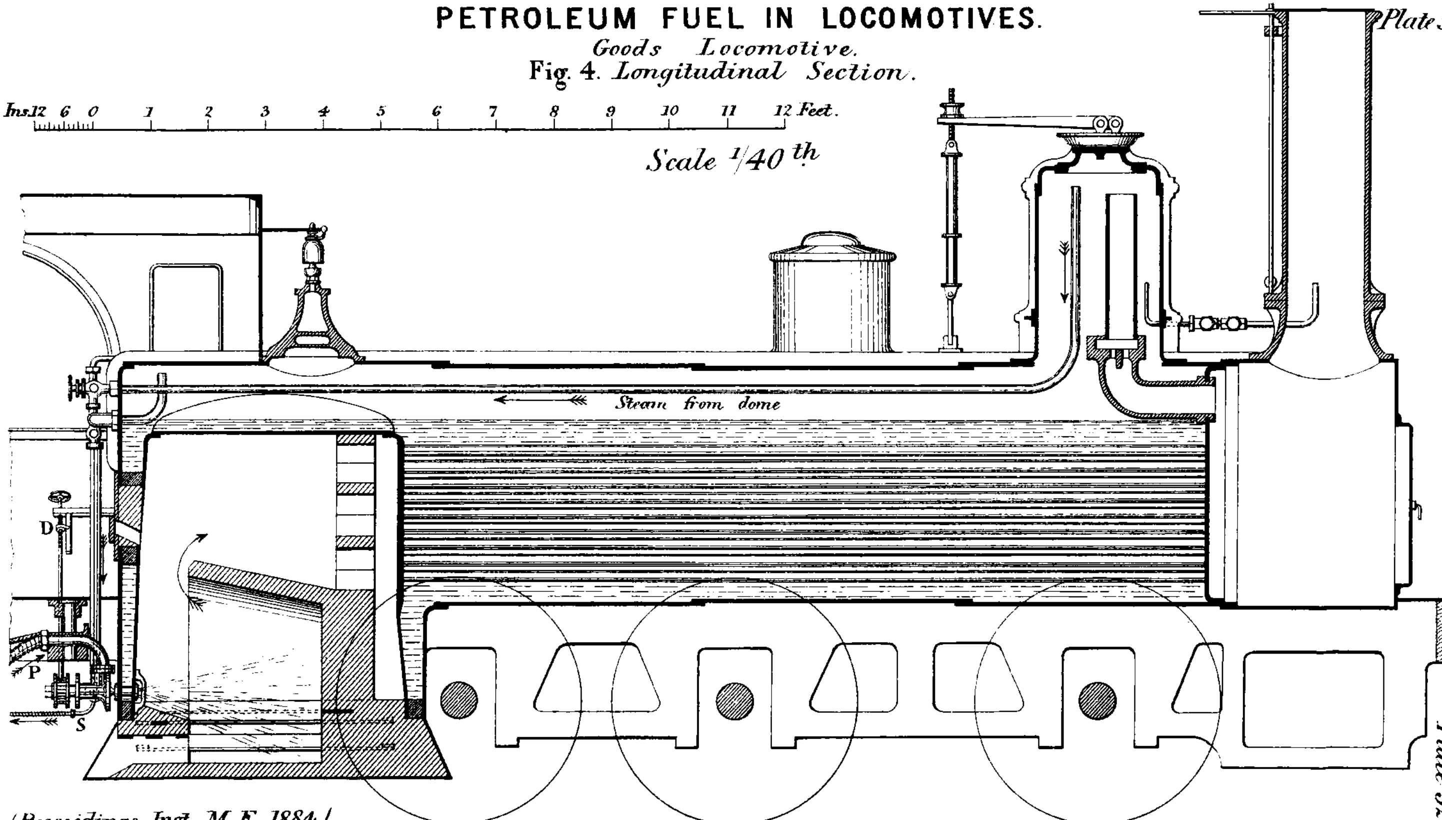
Plate 51.

PETROLEUM FUEL IN LOCOMOTIVES.

Plate 52.

Goods Locomotive.

Fig. 4. *Longitudinal Section.*



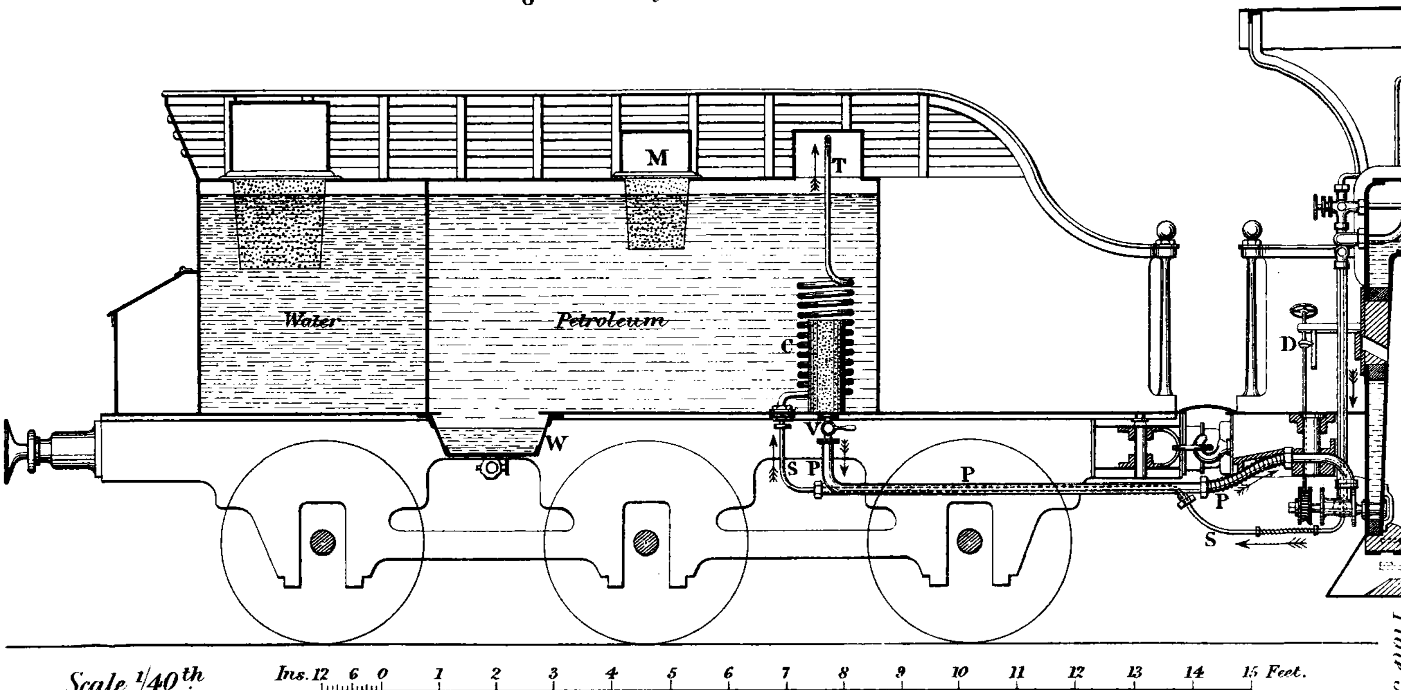
(*Proceedings Inst. M. E. 1884.*)

PETROLEUM FUEL IN LOCOMOTIVES.

Plate 53.

Goods Locomotive Tender.

Fig. 5. Longitudinal Section.



(Proceedings Inst. M. E. 1884.)

Plate 53.

PETROLEUM FUEL IN LOCOMOTIVES.

Combustion Chamber.

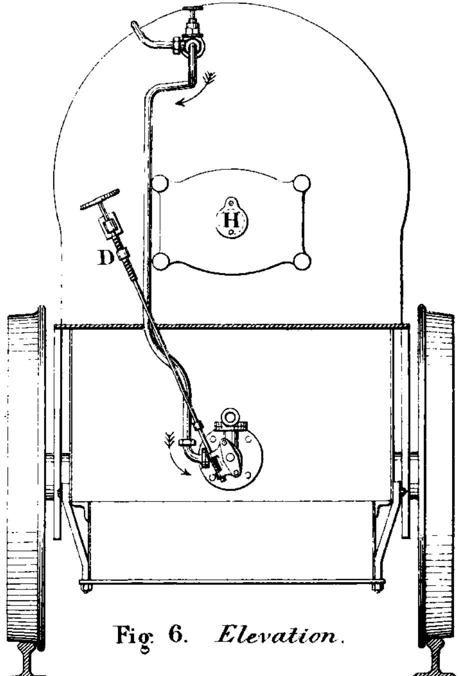


Fig. 6. *Elevation.*

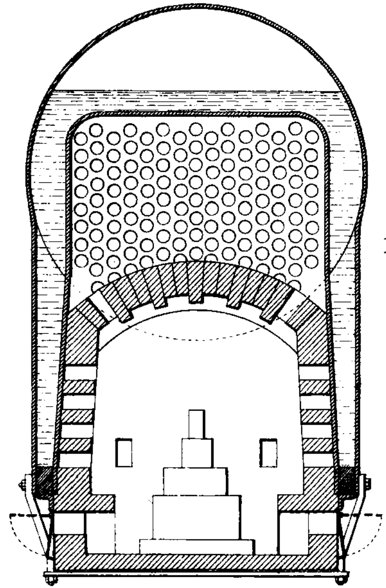


Fig. 7. *Transverse Section.*

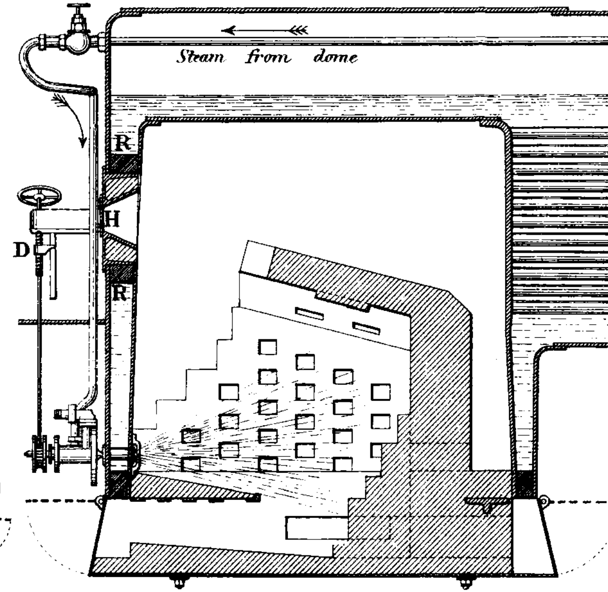


Fig. 8. *Longitudinal Section.*

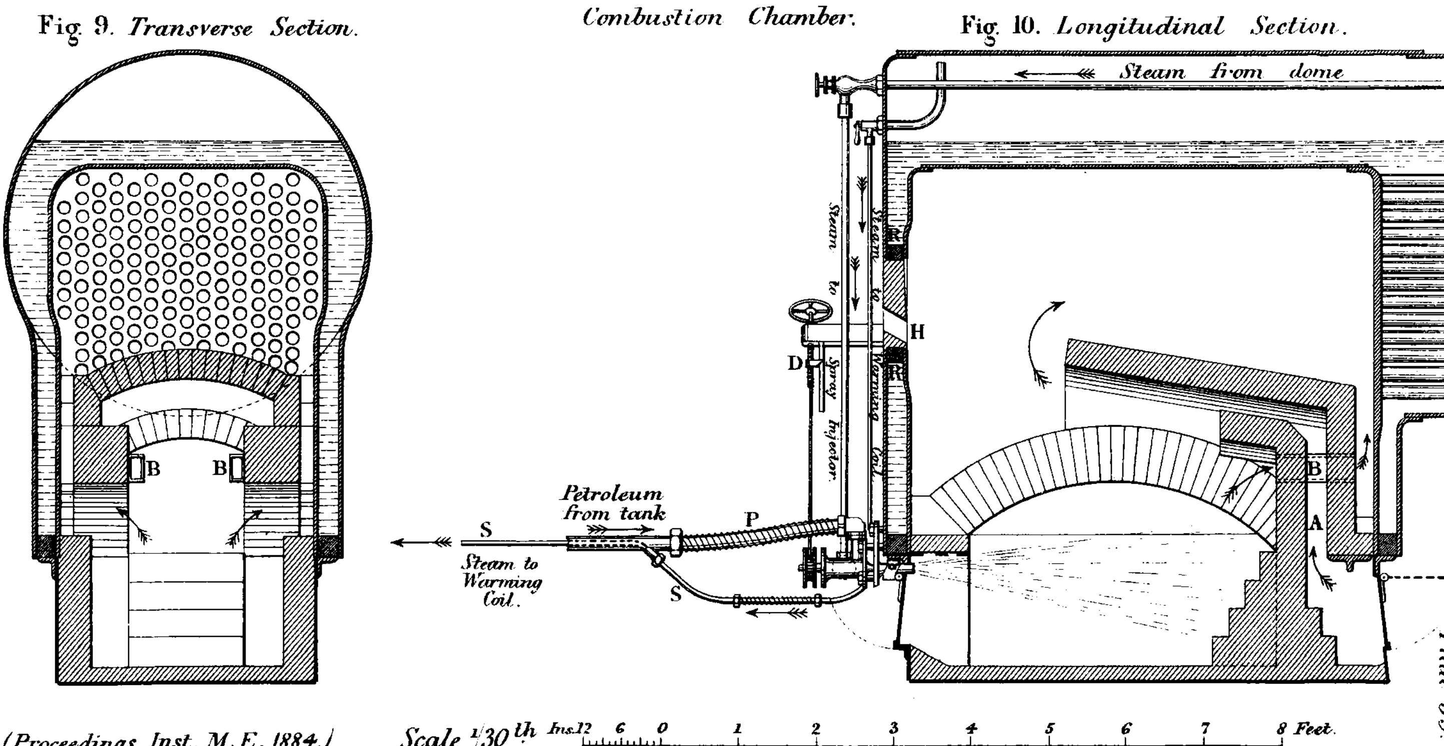
Plate 54.

(Proceedings Inst. M. E. 1884) *Scale 1/30th.* Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

PETROLEUM FUEL IN LOCOMOTIVES.

Plate 55.

Combustion Chamber.



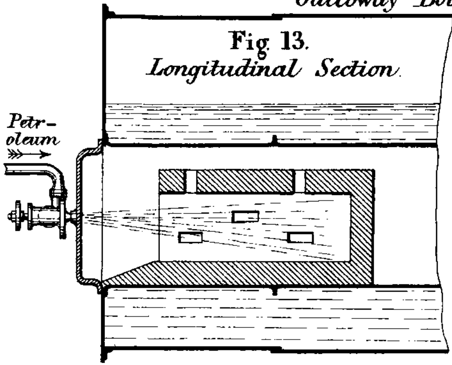
(Proceedings Inst. M. E. 1884.)

Plate 55.

PETROLEUM FUEL IN LOCOMOTIVES.

Plate 56.

Galloway Boiler.



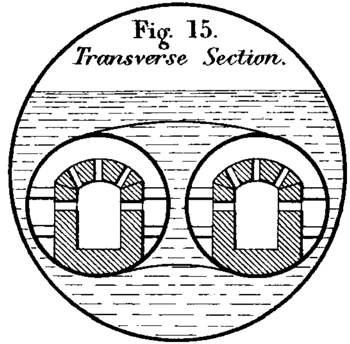
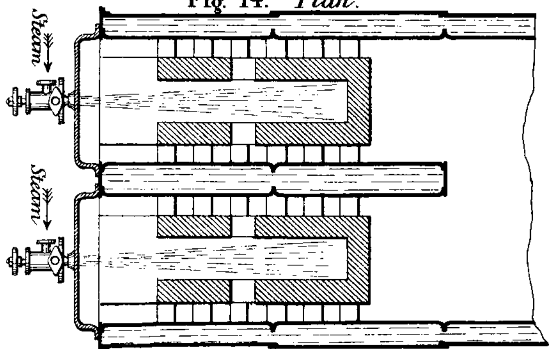


Fig. 14. *Plan.*



Scale 1/48th. 0 1 2 3 4 5 Feet.

Locomotive Combustion Chambers.

Fig. 11. *Plan of Fig. 8.*

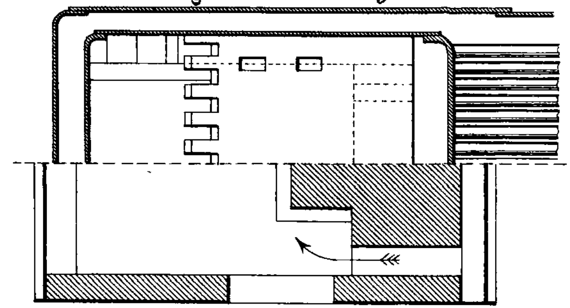
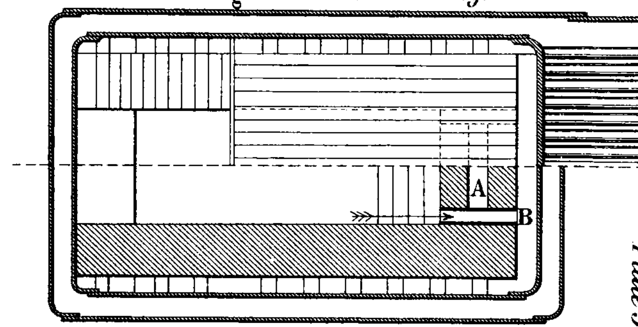


Fig. 12. *Plan of Fig. 10.*



Scale 1/30th. 0 1 2 3 4 5 Feet.

(Proceedings Inst. M. E. 1884.)

Plate 56.

Fig. 16. *Plan of Spray Injector.*

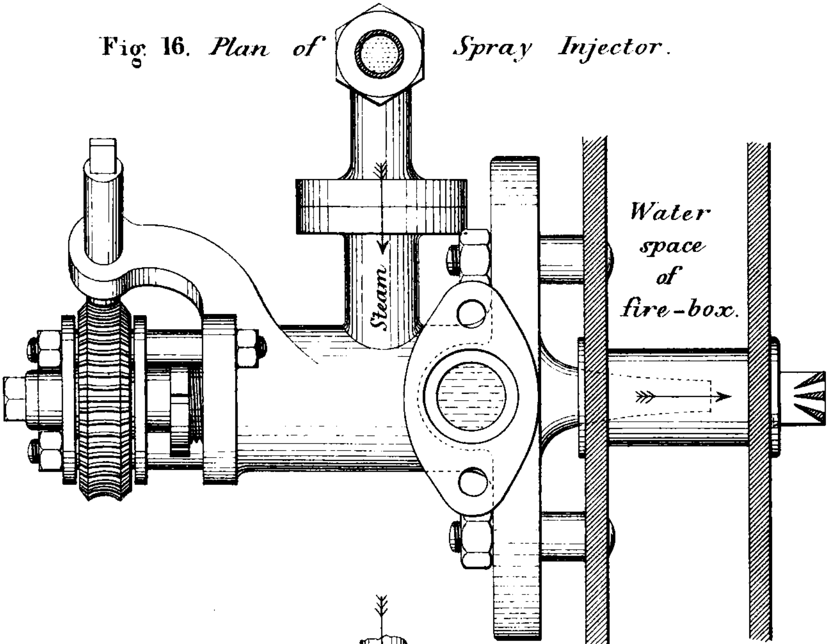
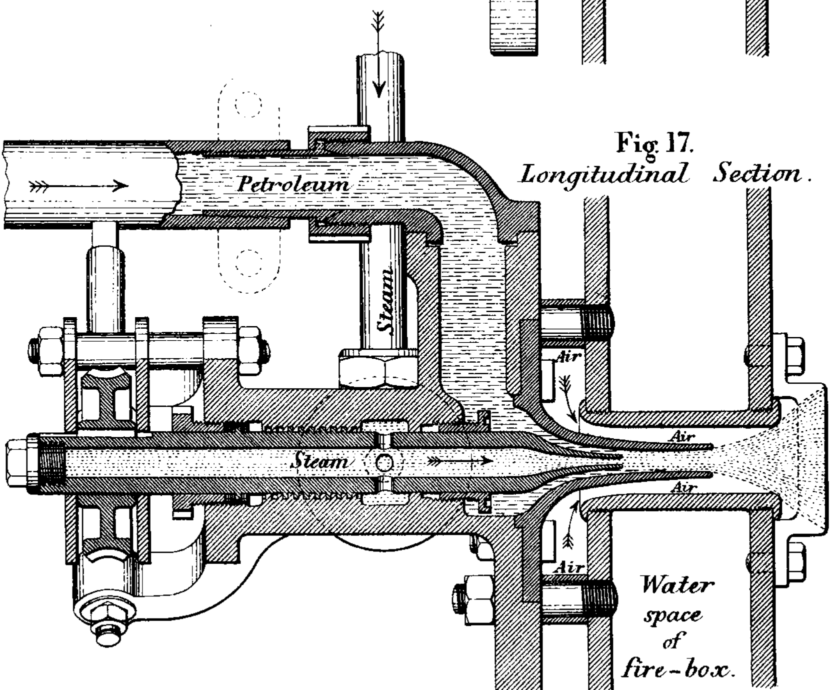
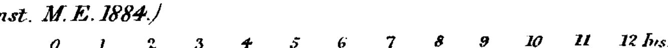


Fig. 17. *Longitudinal Section.*



(Proceedings Inst. M. E. 1884.)

Scale 1/4 th.



PETROLEUM FUEL IN LOCOMOTIVES.

Distributing Tank.

Fig. 18. Elevation.

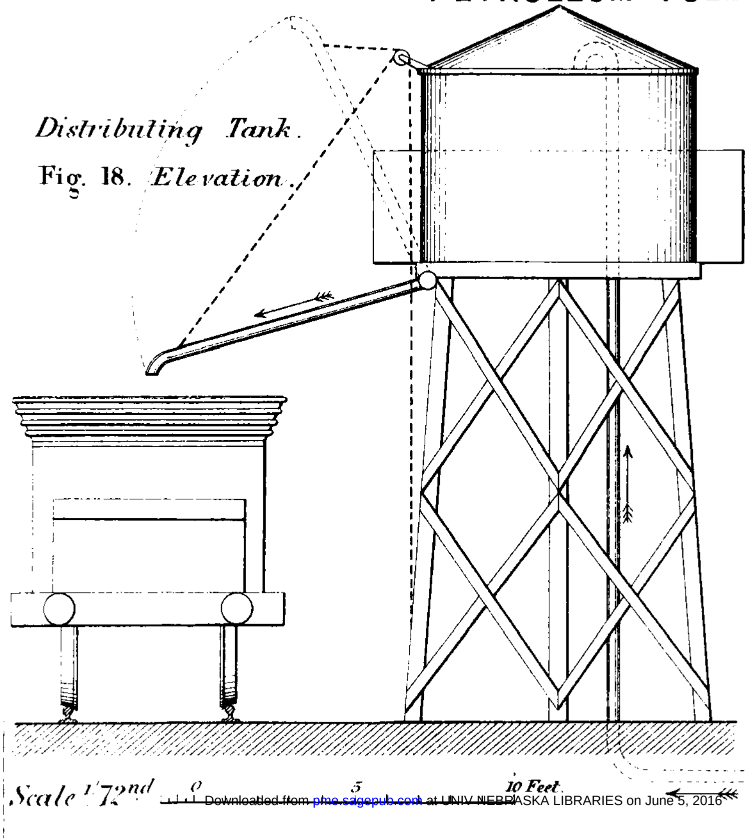
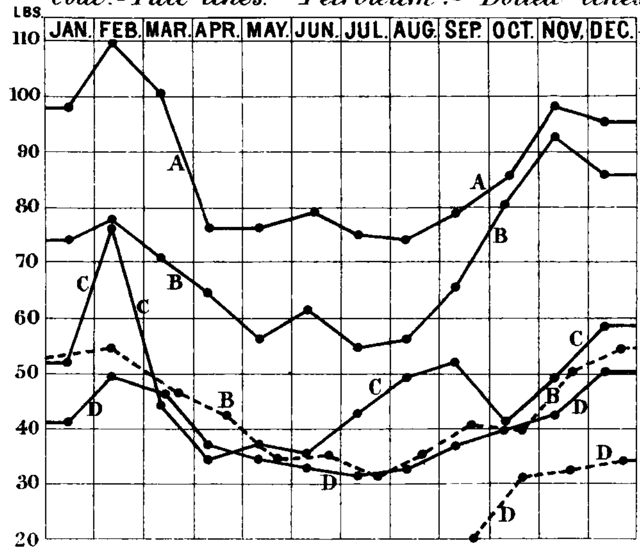


Fig. 19. (See Table VI.)

Consumption of Fuel per Train - Mile.

Coal:- Full lines. Petroleum:- Dotted lines.



A	Goods	Engine,	8	wheels	coupled,	Goods Train.
BB	"	"	6	"	"	" "
C	Mixed	"	4	"	"	Mixed "
DD	"	"	4	"	"	Passenger "

(Proceedings Inst. M. E. 1884.)

Plate 58.

PETROLEUM FUEL IN LOCOMOTIVES. *Plate 59.*

Fire for heating Tyres.

Fig. 20. *Section.*

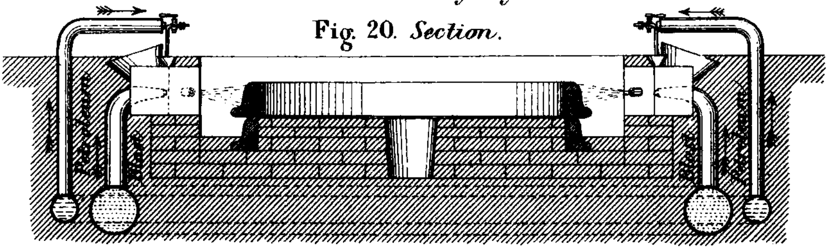
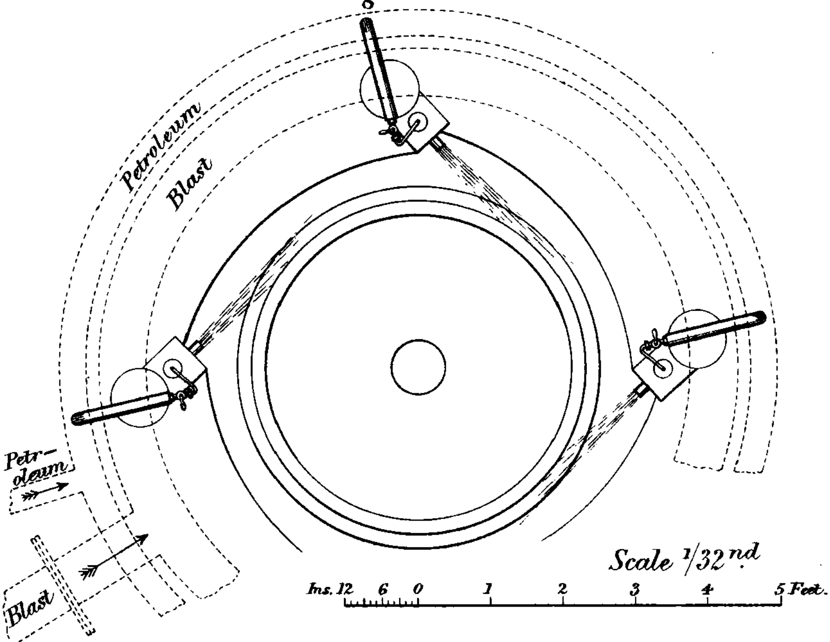


Fig. 21. *Plan.*



Scale 1/32nd.

Fig. 22. *Longitudinal Section.*

Spray Injector.

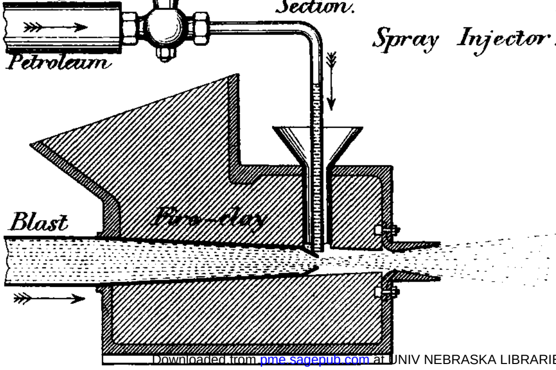
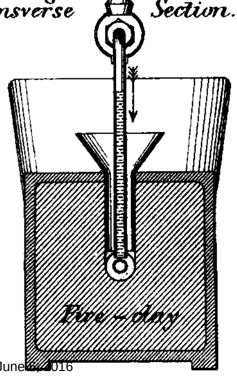
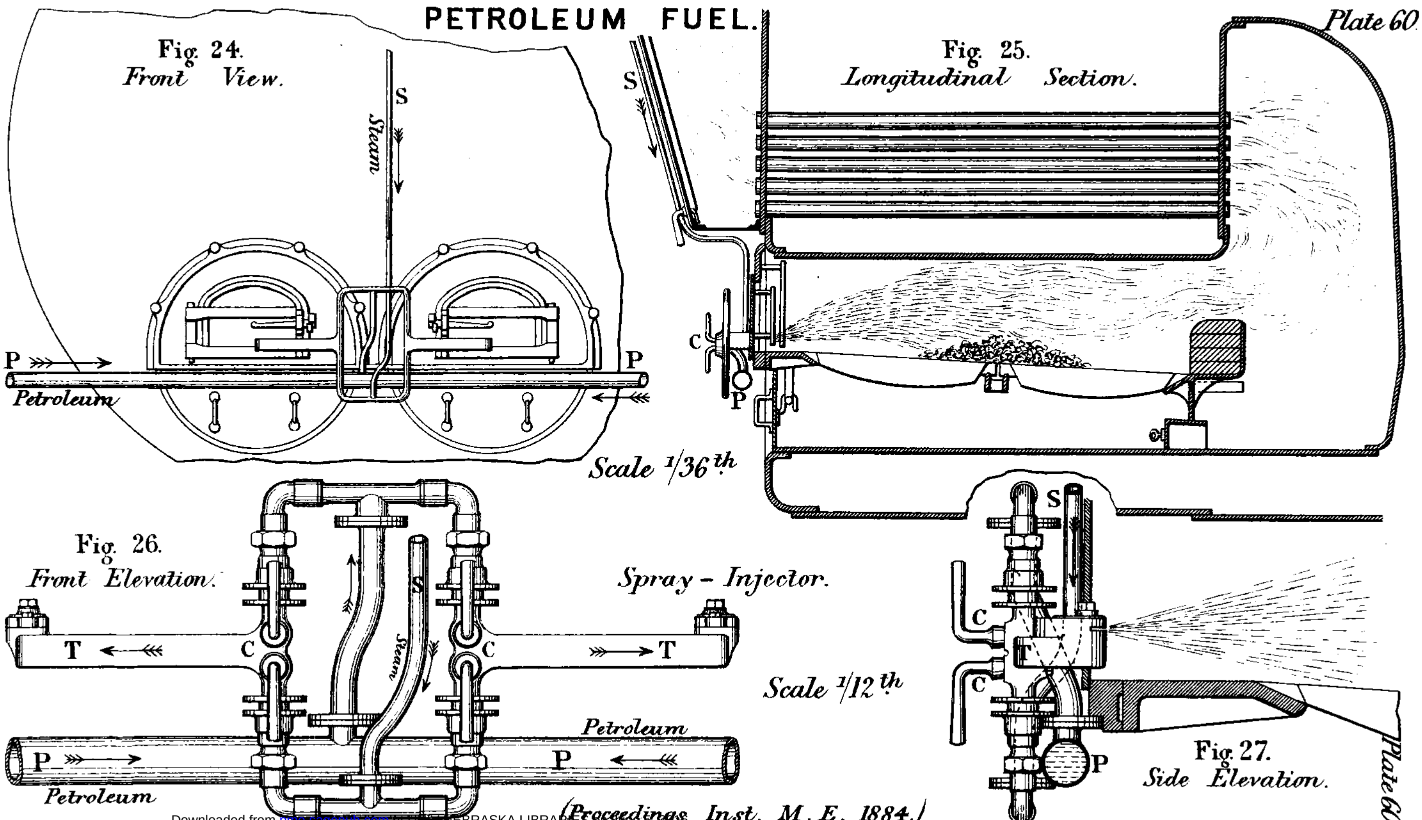


Fig. 23. *Transverse Section.*



Scale 1/8th. 0 5 10 15 20 *Ins.*

(Proceedings Inst. M.E. 1884.)


PETROLEUM FUEL.
Plate 60.
Fig. 24.
Front View.
S
Steam
P
P
Petroleum
Scale 1/36th.
Fig. 25.
Longitudinal Section.
S
C
P
Fig. 26.
Front Elevation.
Spray - Injector.
T
C
S
Steam
C
T
Scale 1/12th.
Petroleum
P
P
Petroleum
S
C
T
C
P
Fig. 27.
Side Elevation.
Plate 60.
(Proceedings Inst. M. E. 1884.)