

ON GIFFARD'S INJECTOR FOR FEEDING STEAM BOILERS.

BY MR. JOHN ROBINSON, OF MANCHESTER.

The object of the Water Injector forming the subject of the present paper, called by the inventor M. Giffard of Paris the "automatic injector," is to feed steam boilers by a self-acting apparatus, employing the direct application of the steam from the boiler without the intervention of machinery, and ready for action at all times independent of the working of the engine, and free from the liability to derangement and the wear and tear incidental to machinery in motion. This injector has attracted special attention, both from the importance of the object aimed at and the success with which this object has been attained, as well as from the novelty and singular nature of its action and the great simplicity of its arrangement; it has proved so completely successful in practical working that its use is now rapidly extending for various classes of boilers.

The construction of the injector is shown by the specimen exhibited and by the accompanying drawings, Plates 5, 6, and 7. Fig. 1, Plate 5, is a vertical section of an injector of the dimensions usually fixed upon locomotives, and Figs. 2 and 3 are transverse sections; Fig. 4, Plate 6, is an enlarged vertical section of the conical steam and water passages. Figs. 11 and 12, Plate 7, show the application of the injector to stationary or marine boilers and locomotives.

The steam from the boiler is admitted through the pipe A furnished with a cock B, and passes down through the perforated cylinder or tube C, which is made conical at the bottom, the area of the aperture being regulated by the conical rod D adjusted by the screw and handle E. The jet of steam issuing from the orifice of the tube C encounters the feed water in the chamber F, which enters from

the feed pipe G ; the supply of feed water is regulated by raising or lowering the tube C by means of the handle H and screw of quick pitch. The stream of feed water propelled by the steam jet issues from the upper orifice I, and passes into the mouth of the lower pipe K leading into the boiler, the intervening space L being open to the atmosphere, so that the stream of water can be seen through the sight holes M at this part of its passage while the injector is at work. A check valve is inserted at N, to prevent the return of the water from the boiler when the injector is not working. The overflow pipe O carries off any overflow occasioned in starting the injector to work, and the sight holes M are covered by a circular slide.

In starting the injector to work, the handle H is first turned into the position suited to the pressure of steam in the boiler ; this permits the access of water to the instrument and regulates its admission. The steam cock B is then opened, and the handle E turned slightly so as to elevate the screwed rod D, which admits a small quantity of steam to the conical opening I. A partial vacuum is thus produced in the chamber F by the rush of steam through the opening I, and the water flows into it. As soon as this happens, which can be observed at the overflow O, the screwed rod D is gradually raised until the overflow ceases, thus giving full liberty to the steam to act upon the water at I and drive it into the boiler through the pipe K and the valve N.

The supposed relative movements of the steam and water when the injector is in perfect action are shown in Figs. 1 and 4, Plates 5 and 6. Fig. 5, Plate 6, shows the result of an excess of steam, and Fig. 6 of an excess of water. In case of an excess of steam, Fig. 5, the opening I is entirely filled by it and the water forced back through the pipe G, the steam escaping through the overflow O. In case of an excess of water, Fig. 6, the quantity of steam rushing from the orifice of the tube C is so small in proportion as not to permit of its reaching the orifice I before it becomes entirely condensed ; its velocity is thus lost, and there is not power enough left to overcome the resistance of the pressure in the boiler, and the water escapes at the overflow O.

The injector has now been in use upwards of nine months in France, a large number having been put to work there, of which a considerable proportion have been applied to locomotive engines; and these have been found so thoroughly satisfactory that their application to locomotives, as well as to marine, stationary, and agricultural boilers, is being widely extended: they are especially advantageous for boilers in motion and when the engines work at high velocities, on account of the certainty of their action together with their great simplicity of construction and freedom from risk of derangement. Injectors have been working for six months in England, the first having been procured from France by the writer's partner, Mr. Stewart, and tried upon a stationary boiler at their works. It was subsequently put to work upon a ballast engine upon the St. Helen's Railway, where in the course of a few days the driver was able to dispense with the use of the engine pumps, and to maintain the level of the water in the boiler by the injector alone. A larger injector was then tried upon a goods engine on the same railway, which proved entirely successful: and the writer, with the kind co-operation of Mr. Cross, the engineer of the railway, made experiments with this and another injector of the same size manufactured at Manchester, to ascertain what effect the temperature of the feed water, the vibrations and concussions caused by the action of the break, passing over crossing points or shunting wagons, would have upon the regularity of the water passing through the instrument. The general result ascertained by these experiments was that the injector would work at all steam pressures up to the maximum working pressure of the boiler, 110 lbs. per square inch; and would draw water from the tender of any temperature up to 110° Fahr.; and that neither the sudden application of the break, nor any shock produced in passing bad points or in shunting, interfered in any way with its efficient working. The only difficulty which arose was when the water in the tender had become hot and at the same time very low in level, under which circumstances conjoined the degree of vacuum capable of being produced in the water chamber of the injector was not sufficient to lift the water to the height at which it was placed, 29 inches above the footplate; this inconvenience however was readily obviated by lowering the

injector so as to bring the water entrance within a few inches of the level of the bottom of the tender. In using the injector no difficulty was experienced in so regulating the openings for steam and water as to produce a constant and regular supply of any required quantity of water to the boiler without waste from the overflow pipe. The result of the continued working of these injectors on the St. Helen's Railway was so satisfactory that ten of them have been ordered for the engines on this railway: and it has been decided to replace all the pumps of the locomotives on a foreign railway by injectors, after careful trial of one of them; and one injector only is to be placed on each of eight locomotives now being built for the same railway at the writer's works, the pumps being dispensed with altogether.

It may be desirable here to mention some collateral advantages arising from the use of the injector on locomotive engines. The space hitherto occupied by the pumps is saved, and becomes available for other purposes: the power of the engine required to work the pumps is economised, and the wear and tear of the parts through which this power is transmitted is entirely avoided: and the water level can be maintained at any desired height whether the engine is moving or not; also the steam often blown off when standing can be used for the purpose of forcing water into the boiler.

Several sizes of injectors are made to suit different purposes: that generally adopted for locomotives, as shown in Fig. 1, Plate 5, measures 8 millimetres or 0.32 inch in the smallest diameter of the throat K. This diameter is taken as the standard point of measure for the power of the instrument, and the designation of the dimensions of the French injectors in millimetres has been adhered to by the writer, from the convenience of the decimal system of measurement. The size of 8 millimetres throat is called No. 8 injector; another size No. 6 of 6 millimetres throat being made for stationary boilers of ordinary size and pressure, and corresponding smaller ones No. 4 and No. 2 for smaller boilers and for agricultural and portable engines: a larger size No. 10 of 10 millimetres throat is designed for large locomotive and other boilers of great evaporating power. In the case of a goods engine drawing a load of 24 wagons up a gradient of 1 in 96 about 2 miles long on the East Lancashire Railway,

Mr. Lees has found that all the water given off by evaporation during the ascent could be easily replaced by a No. 8 injector, without reducing the steam pressure 1 lb. ; the initial pressure of 100 lbs. having been maintained during the whole time, and rising immediately the summit was attained.

For the purpose of ascertaining the limits of the circumstances under which the injector can be worked, a series of experiments have been made by the writer with instruments of different sizes fixed to stationary boilers working at 60 lbs. pressure; one of which being connected with an adjoining boiler in which the pressure could be reduced to any desired amount gave great facility for measuring the power of the injector when feeding by lower into higher pressures : the relative pressures being accurately observed by Schaeffer's and mercurial steam gauges. The temperature of the feed water also could be varied at pleasure, by introducing into it either hot or cold water as required. The general results obtained from these experiments were, that water could be forced into a boiler by the injector when the steam pressure was not below 5 lbs. per square inch ; that the temperature of the feed water might be raised up to 148° Fahr., requiring to be varied in the inverse proportion to the pressure of steam ; and that surplus power was developed by the instrument, available for forcing water into a boiler at a higher pressure than the one from which the steam was obtained, the injector having been effective with steam of 24½ lbs. pressure above the atmosphere in forcing water into a boiler at 48½ lbs. pressure. The particulars of these experiments are given in the following tables : in all cases the surface of the water in the supply tank was at least 2 feet below the level of the water chamber of the injector, the vacuum in that chamber being from 1 lb. to 1½ lbs. below the atmosphere during the operation.

Table I shows approximately the maximum temperature of feed water hitherto capable of being used at various pressures of steam :—

TABLE I.

*Maximum Temperature of Feed admissible
at different Pressures of Steam.*

Pressure of Steam, lbs. per square inch	10	20	30	40	50	100
Temperature of Feed, Fahrenheit	148°	138°	130°	124°	120°	110°

These circumstances in the action of the injector render its application to the supply of marine boilers particularly advantageous, since the low pressure at which they usually work, and the fact that the feed water has not to be drawn up from a lower level, enable a high temperature to be imparted to the water without endangering the regularity of the feed ; besides which the simplicity and certainty of action of the injector obviates the inconvenience and danger arising from the failure of the donkey and other pumps now usually employed for feeding these boilers. It will readily be seen that the instrument has all the advantages sought in the use of donkey pumps, by its ability to feed the boilers quite independently of the movement of the engines ; and also that it utilises all the steam which it draws from the boiler, in raising the temperature of the water while passing through the injector itself.

Table II shows the quantity of water in gallons per hour which a No. 4 injector is capable of delivering at various steam pressures, the temperature of the feed water being 95° Fahr. :—

TABLE II.

Quantity of Water Delivered at different Pressures of Steam.

Pressure of Steam, lbs. per square inch	5	10	20	30	40	50	60
Water Delivered, gallons per hour.....	93	124	150	186	210	244	259

As an addition to this experiment it may be stated that with a No. 8 injector working at a pressure of 150 lbs. per square inch as much water was passed through the throat of 8 millimetres or 0.32 inch diameter as was supplied to the tank by a pipe of 1½ inch bore from a cistern at least 20 feet higher than the tank.

Table III shows the quantity of water in gallons per hour delivered by a No. 8 injector according to the temperature of the feed water employed, the steam pressure being constant at 60 lbs. per square inch :—

TABLE III.

Quantity of Water Delivered at different Temperatures of Feed.

Temperature of Feed, Fahrenheit	60°	90°	105°	120°	130°
Water Delivered, gallons per hour	972	786	698	486	382

Table IV supplies a measure of the power of the instrument by showing the excess of pressure which may exist in the boiler fed by the injector above that of the steam used for working the injector :—

TABLE IV.

*Low Pressure boiler supplying High Pressure boiler :
Maximum Difference of Pressure admissible.*

Temperature of Feed.	Pressure of Steam.		Difference of Pressure.	Result.
	Low Pressure.	High Pressure.		
74°	Lbs.	Lbs.	Lbs.	
	50	59	9	
	40	55½	15½	Slight overflow.
86°	38	56½	18½	Overflow increased.
	86	57	21	Delivery almost ceased.
74°	50	51½	1½	
	37	49	12	Slight overflow.
	33	50½	17½	Overflow increased.
96°	30	52½	22½	Delivery almost ceased.
74°	45	47	2	
	34	45½	11½	Slight overflow.
	31	45½	14½	Overflow increased.
106°	24	48½	24½	Delivery ceased.

The following is an approximate rule used by the inventor, derived solely from experiments in France, for calculating the quantity of water which can be delivered for non-condensing engines by an injector having a given diameter of throat :—

$$Q = 6.16 \, d^2 \sqrt{p}$$

Q being the quantity of water delivered in gallons per hour, d the diameter of throat in millimetres, and p the pressure of steam in atmospheres. The size of injector for a given nominal horse power of boiler is ascertained from the converse rule :—

$$d = \sqrt{\left(\frac{Q}{6.16 \sqrt{p}} \right)}$$

The above experiments are given only as approximations for general guidance, since they are not considered by the writer sufficiently accurate for the purposes of exact calculation as to the action of the injector.

It may not be out of place now to suggest a theory according to which the injector is supposed to act. The pressure on all parts of the interior of steam boilers being equal, some reason must be sought why steam taken from one part is able to overcome the resistance opposed to its entrance into another part of the same boiler. Looking at the construction of the instrument itself, it is evident that when it is in operation, and the valve N , Fig. 1, open or removed, the pressure in the boiler acting through the pipe K appears free to resist the entrance of the water into it. It may be assumed that steam or water escaping from a boiler into the atmosphere does so at a velocity proportioned to its pressure or density, as in diagrams 7 and 8, Plate 6. If a pipe conveying steam were turned directly back into the water of the same boiler, it is evident that equilibrium would ensue and no effect be produced. If on the other hand a break were made in the continuity of the pipe so as to leave an interval open to the atmosphere, the steam would rush from one pipe and the water from the other at velocities proportioned to their different densities. But in the construction of the injector the feed water chamber F is placed at this break in the pipe, as shown in diagrams 9 and 10 and Figs. 1 and 4; and this arrangement accounts for the power of the steam to

overcome the resistance to its entrance into the receiving pipe below : for the jet of steam being concentrated on the water at I forces its way through the interval L surrounded by the feed water, by contact with which it is gradually condensed and reduced in volume and velocity until it is entirely converted into water at the throat K ; while by this contact with the steam from I to K the feed water has a velocity imparted to it proportioned to the steam pressure in the boiler and its own temperature; and being nearly non-elastic it thus acquires momentum sufficient to overcome the resistance of the water in the boiler.

This explanation will perhaps also serve to account for steam of lower pressures being better adapted to act upon water at higher temperatures, since the lower the pressure of the steam the less must be its velocity in passing from the orifice I to the throat K, and consequently the more time will be given for its condensation, a condition necessary when the higher temperatures of feed water are used. This explanation also agrees with the fact that the higher the steam pressure the more rapid is the stream of feed water into the boiler, since in passing from the orifice I to the throat K at a higher velocity and at a higher temperature, a larger volume and a lower temperature of water are required to condense the steam jet; and its capacity for this water being in proportion to its temperature, the quantity of feed carried into the boiler is proportionately increased.

It has not been attempted to give any calculation of the power obtained by the injector; and indeed the writer has been discouraged from attempting this by the opinion expressed to him by an eminent hydraulic engineer, that the injector is a valuable application of a force which very few persons understand and which has never been explained in books. And when it was found possible with steam of 24 lbs. pressure to inject water into a boiler at 48 lbs. pressure, it was felt that it would be premature to bring forward calculations based upon the result of experiments so hastily made, which require much consideration and discussion before any safe conclusions can be arrived at.

Mr. C. W. SIEMENS enquired what increase of temperature took place in the feed water in passing through the injector, as this would be a measure of the quantity of steam condensed in the jet, and it was important to ascertain the actual expenditure of power in working the instrument. The theory of its action could then be investigated by ascertaining whether the quantity of steam condensed in the jet was sufficient to impart to the jet of water the velocity required for enabling it to overcome the resistance opposed to its entrance into the boiler : for the velocity imparted would be inversely proportionate to the weights in motion, and 1 lb. of steam would impart to 10 lbs. of water 1-10th of its velocity, if no force were lost from friction and eddies in the jet.

Mr. ROBINSON replied that there was found to be a rise of temperature of about 60° in the water in passing the injector, the feed water at 100° being raised to 160° . He showed a specimen of the injector, taking it to pieces to show the construction.

Mr. E. A. COWPER asked whether this rise of temperature was measured from the waste water overflowing from the instrument, or from the water in the feed pipe going into the boiler : the latter he considered would be requisite for obtaining the correct result. The instrument was certainly highly ingenious and an interesting subject for investigation as to the principle of its action.

Mr. ROBINSON said the rise of temperature that he had mentioned had been measured only at the overflow, as there was no means of measuring it otherwise at present.

Mr. F. J. BRAMWELL asked whether the working of the injector could be so controlled as to have no overflow.

Mr. ROBINSON replied that the overflow was entirely stopped by adjusting the steam and water in due proportion, which took place in a few seconds after starting to work, and the injector then continued working regularly for any length of time without the least overflow with a pressure continuing uniform ; but the overflow could be caused directly by increasing the water supply or diminishing the steam too much.

Mr. W. B. JOHNSON had seen the injector at work, and was much struck with its perfect action and extreme simplicity ; it was started

instantaneously to work without any difficulty, and continued working regularly without the slightest overflow of water; the sight holes could be kept permanently open after it was started in full work, and all that was seen was an apparently solid column of water rushing from one tube into the mouth of the other. He saw an experiment tried whilst the injector was in full work, by inserting a plate between the two orifices to stop the action of the jet; but the stream was instantly established again on removing the interrupting plate.

Mr. C. MARKHAM said he had seen the injector working on two stationary boilers at Manchester, and its action was certainly most effective and perfect; the supply to the boiler was kept up without any interruption or difficulty. Its action was no doubt due to the high velocity imparted to the feed water by the steam jet, which was sufficient to carry it into the boiler. An important practical advantage of the instrument was that there was nothing about it liable to get out of order: the only fear he felt was of incrustation from the water accumulating at some part and obstructing the passage through it; for in all boilers a serious incrustation took place around the orifice where the feed water entered, caused by deposit of the earthy matter from the suddenly heated and evaporating water at the moment of entering the boiler: in some cases this incrustation was so great in the course of a short period as to contract a $1\frac{1}{2}$ inch opening to $\frac{1}{4}$ inch or even less in diameter.

Mr. ROBINSON replied that not the least difficulty of this kind had been experienced with the injector; he had tried it after 4 months' work and found no difference perceptible in the diameter of the orifice, and indeed any deposit in the tubes would be inevitably cleared away by the great force of the jet the first time it was started again; and the heating effect of the boiler did not reach the injector. The construction of moveable cones sliding one within the other adopted in the injector effectually prevented any difficulty arising from small orifices, since the actual openings were large, though admitting of regulation down to the smallest size.

Mr. F. J. BRAMWELL thought the action of the instrument was entirely due to the velocity imparted to the feed water by the jet of steam; it might be illustrated by supposing a cistern of water with

several feet head to supply a jet in the position of the lower part of the instrument, and another jet from a higher cistern to be then brought opposite to the first in the position of the upper part of the instrument, when the greater velocity of the upper jet would necessarily overpower the lower one, and the water would force its way into the tube of the lower jet. Now in the case of the injector, if the velocity imparted by the jet of steam to the feed water in the upper jet were greater than that at which the boiler water would escape from the lower tube if unopposed, the water must be forced into the boiler; and since the velocity of the steam was so much greater than that of the water issuing from the same boiler, in consequence of its greatly reduced density, the steam jet was able to impart a sufficient excess of velocity to the feed water to force it into the boiler. Increased velocity was indeed in this case made to produce an increased pressure, as in the case of the water ram: only that in the injector the propelling steam was all condensed and got rid of continuously, instead of the actuating water stream being discharged intermittently as in the water ram.

Mr. ROBINSON observed that a singular circumstance had been noticed in the working of the injector, that when it had got cold it would not start at once, but required warming by blowing steam through for a few moments; then after shutting the steam off, it started to work all right in two or three seconds when the steam was turned on again.

Mr. F. J. BRAMWELL asked whether the injector had been tried without having to raise the feed water by suction; and what difference there was then found to be in the temperature of feed water that could be used.

Mr. ROBINSON replied that an injector had been in constant use some time at his works which was supplied by a cistern at 20 feet head above it, and there was no difference or difficulty attending its action when the opening for the water supply was regulated accordingly: there was no opportunity for trying the limit of temperature in that instance. That injector was employed in feeding a boiler on the locomotive construction working at 60 lbs. pressure; and he had also tried one of No. 8 size on a large locomotive engine at 140 lbs. pressure, and it worked perfectly well, and raised the water in the

boiler 3 inches in 4 minutes, the steam blowing off freely at the time.

The SECRETARY had witnessed many of the experiments with the injector described in the paper, and could confirm the accuracy of the results given.

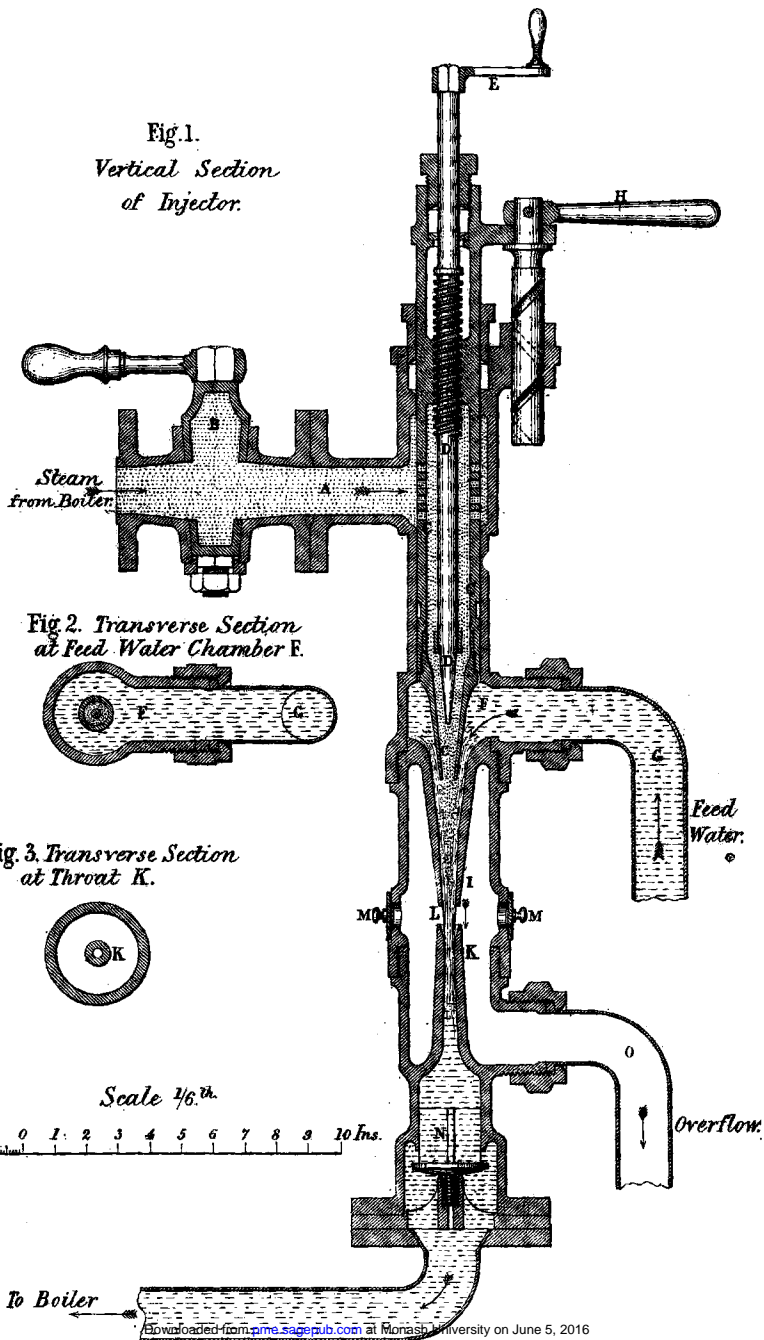
Mr. H. MAUDSLAY thought that in applying the injector to marine boilers, although its action might be entirely safe and reliable, it would not be advisable to do away with the donkey engines; for independent of their value as an additional precaution they were very useful for other purposes, such as pumping bilge water and as fire-engines, &c.

Mr. ROBINSON observed that the injector was equally capable of being applied to raising the bilge water or throwing a fire jet, as it discharged a steady jet of water from the delivery pipe; but it was not suited probably as an economical application of power for a fire-engine jet, and the heated water might be objectionable for leather hose.

The CHAIRMAN proposed a vote of thanks to Mr. Robinson for his paper, which was passed.

The Meeting then terminated, and in the evening a number of the Members and their friends dined together in celebration of the Thirteenth Anniversary of the Institution.

Fig. 1.
Vertical Section
of Injector.



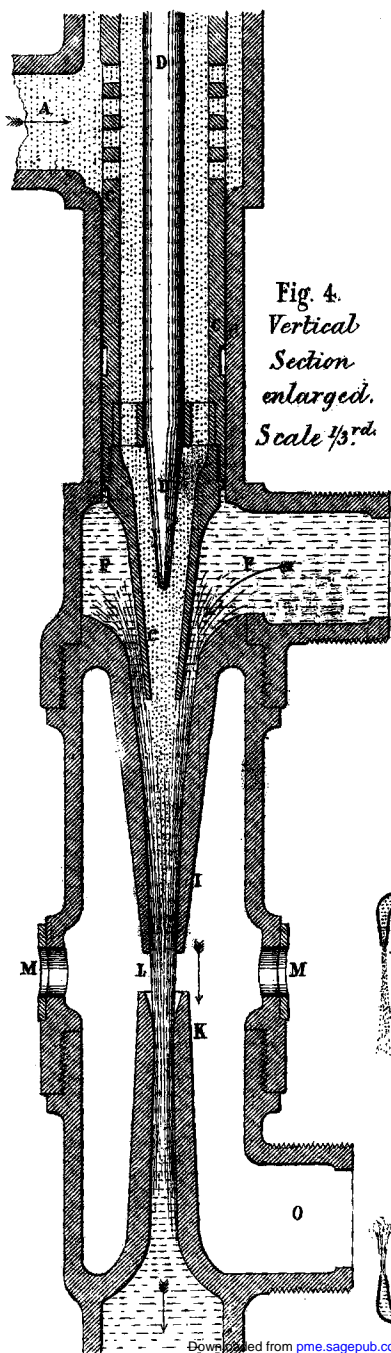


Fig. 5.
Excess of Steam.

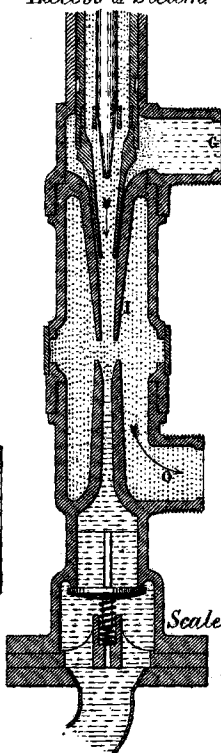
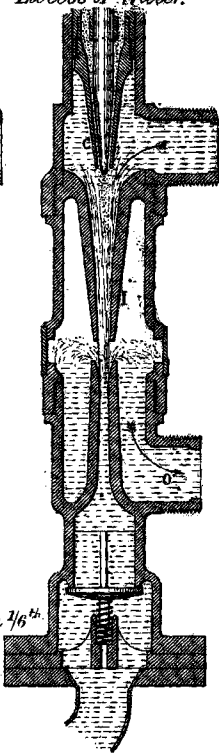


Fig. 6.
Excess of Water.



Scale $\frac{1}{6}^{th}$

Fig. 7.

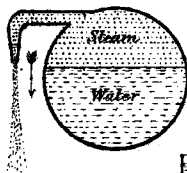


Fig. 9.

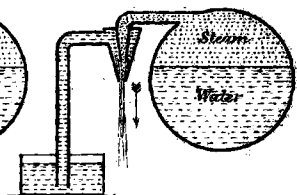


Fig. 8.

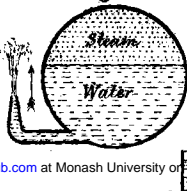
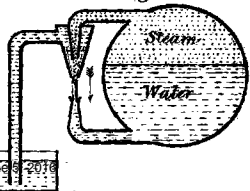
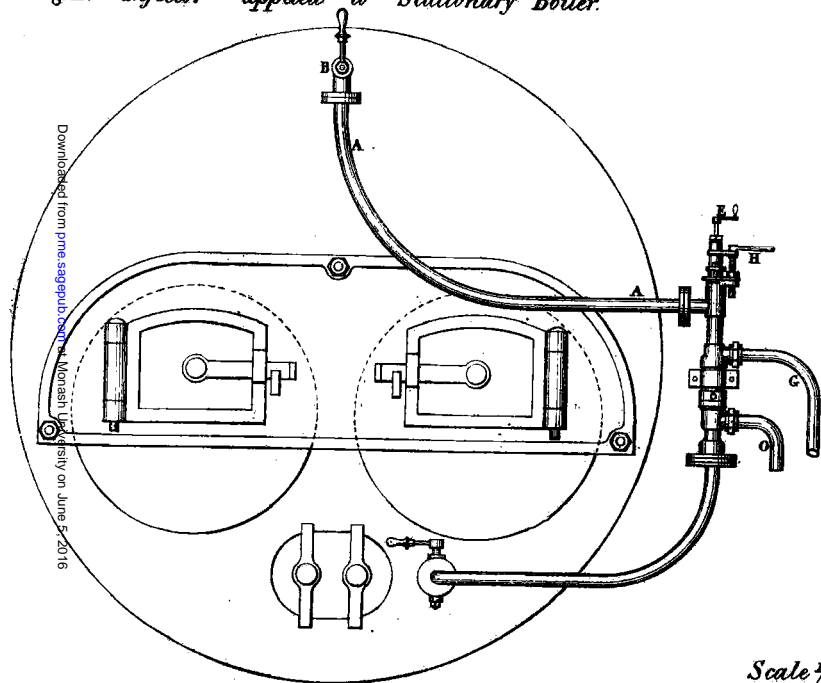


Fig. 10.



BOILER INJECTOR.

Fig 11. *Injector applied to Stationary Boiler.*



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(Proceedings Inst. M.E. 1860. Page 39.)

Scale $\frac{1}{25}^{th}$.
0 10 20 30 40 50 Inches.

Plate 7.

Fig 12.
Injector applied to Locomotive Boiler.

