

ON A STEAM JET
FOR EXHAUSTING AIR &c.,
AND THE RESULTS OF ITS APPLICATION.

BY C. WILLIAM SIEMENS, Esq., D.C.L., F.R.S., PRESIDENT.

The Steam Jet, although it has long been used with such remarkable success for producing a current of air to form an artificial draught in locomotive and portable engine boilers, has hitherto been extremely limited in its application to other purposes; for though its simplicity for the propulsion of air is a great recommendation, the effect realised from a given expenditure of steam has been extremely unsatisfactory, in comparison with the results of the same steam in working an engine and air pump; nor has sufficient pressure of air been obtained from the steam jet to render it applicable for pneumatic propulsion or the production of furnace blast. The form and application of the steam jet having remained hitherto essentially the same as in the original steam blast of the locomotive in 1829, it occurred to the writer that much might be done to improve its effect by a judicious arrangement of the parts, so as to avoid eddies in the combined current of steam and air, and also to utilise more completely the initial momentum of the steam. In carrying out this idea, the first results obtained about a year ago were sufficiently encouraging; and by gradually recognising more fully the points of essential importance, the writer succeeded in constructing a steam-jet exhausting apparatus capable of producing a vacuum of as much as 24 inches of mercury, with steam of only three atmospheres effective pressure; and a useful effect has been obtained from the steam, equal to that of the ordinary fan blast, and even of the steam engine and pump.

This improved steam jet is shown half full size in the longitudinal and transverse sections, Figs. 2 to 5, Plates 13 and 14. A very thin annular jet of steam is employed, in the form of a hollow cylindrical column, discharged from the annular orifice between the two conical nozzles A and B, the steam being supplied from the pipe C into the space between the two nozzles. The inner nozzle A can be adjusted up or down by the hand screw D, so as to diminish or increase the area of the annular orifice between the two nozzles, for regulating the quantity of steam issuing. The air to be propelled by the steam jet is admitted from the pipe E through an exterior annular orifice surrounding the steam jet, and also through the centre of the hollow jet. The tube G, into which the steam jet issues, is made of conical shape at the bottom, so as to form with the outer nozzle B a rapidly converging annular passage for the entrance of the air; and the width of this air passage is regulated by adjusting the nozzle B by means of the nut H at bottom. The tube G continues to converge very gradually for some distance above the jet orifice, the length of the convergent portion increasing with the width of the outer annular air orifice, and also with the steam pressure employed; the most advantageous length varies from 12 to 20 times the width of the annular air orifice, the object being to ensure the complete commingling of the steam and air within the length of the mixing chamber G, beyond which the tube gradually increases in diameter in a parabolic curve to the upper end, as shown in Fig. 1. A tapering spindle I is sometimes fixed in the centre of the inner nozzle A, and carried up through the mixing chamber G, for the purpose of preventing reflux through the centre of the combined current.

The rationale of this arrangement is as follows. First, by gradually contracting the area of the air passages on approaching the jet, the velocity of motion of the entering air is so much accelerated before it is brought into contact with the steam, that the difference in the velocity of the two currents at the point where they come together is much reduced, and in consequence the eddies which previously impaired the efficiency of the steam

jet are to a great extent obviated, and a higher useful result is realised. Secondly, by the annular form of the steam jet the extent of surface contact between the air and the steam is greatly increased, and the quantity of air delivered is by this means very much augmented in proportion to the quantity of steam employed; also the great extent of surface contact tends to diminish eddies. Thirdly, by discharging the combined current of steam and air through the expanding parabolic delivery funnel of considerable length, in which its velocity is gradually reduced and its momentum accordingly utilised by being converted into pressure, the degree of exhaustion or compression produced by the steam jet is very materially increased under otherwise similar circumstances.

The results of a long series of experiments with this form of steam jet, both for exhausting and compressing air, have led to the following conclusions:—

First, that the quantity of air delivered per minute by a steam jet depends upon the extent of surface contact between the air and the steam, irrespective of the steam pressure, up to the limit of exhaustion or compression that the jet is capable of producing.

Second, that the maximum degree of vacuum or of pressure attainable increases in direct proportion to the steam pressure employed, other circumstances being similar.

Third, that the quantity of air delivered per minute, within the limits of effective action of the apparatus, is in inverse relation to the weight of air acted upon; and that a better result is therefore realised in exhausting air than in compressing it.

Fourth, that the limits of air pressure attainable with a given pressure of steam are the same in compressing and in exhausting, within the limit of a perfect vacuum in the latter case.

The principle of action of the steam jet had received but little attention until the time of the interesting question raised in 1858 by the invention of the Giffard Injector, by means of which water can be forced into a high-pressure boiler by a jet of steam of the same pressure, or even of greatly inferior pressure. The physical

T

explanation of this remarkable fact, which was first attempted the writer believes in a discussion of the subject at this Institution (see Proceedings Inst. M. E. January 1860 page 39), is based on the principle of conservation of momentum in the combined jet of steam and water; but although the source of power in both cases is a steam jet, the mode of action in the water injector differs essentially from that of the steam jet applied to propulsion of air, as in the former case the steam is condensed by contact with the water, and ceases to be an elastic fluid at the moment of issue, while in the latter the steam forms with the air a combined elastic stream.

A very elaborate investigation of the ordinary steam jet applied to propulsion of air was given by Professor Zeuner of Zurich in 1863, showing the effects produced by varying the relative areas of inflow of the air and steam, and varying the steam pressure employed. These theoretical enquiries, which were supported by elaborate experiments, have since been considerably advanced by Professor Rankine, who has shown that in the combined stream a considerable portion of the total momentum is lost, and that the relative proportion of this loss increases with the difference of velocity between the component streams.

The form of steam jet employed in Zeuner's experiments consisted of a contracted steam orifice, directed upwards in the line of the axis of a vertical delivery tube, but terminating a little below the base of the tube; the length of the tube relatively to its diameter was found to be only of minor importance. Exhaustion of air was effected at the lower end of this delivery tube, or compression of air at the upper end. The greatest extent of exhaustion or compression that was maintained with steam of two atmospheres effective pressure amounted to 7 inches of mercury; and 100 volumes of steam measured at atmospheric pressure were expended in compressing only 7 volumes of air to the above pressure of about $\frac{1}{4}$ atmosphere. With a reduced orifice for the steam jet, a compression of $3\frac{1}{4}$ inches of mercury was maintained, and 37 volumes of air were compressed by the expenditure of 100 volumes of steam measured at atmospheric pressure.

In a corresponding experiment made with the improved steam jet shown in Plate 13, maintaining a vacuum of $3\frac{1}{4}$ inches of mercury, 137 volumes of air were removed by the expenditure of 100 volumes of steam, both measured at atmospheric pressure; which gives a result of nearly four times the useful effect that was obtained in Zeuner's apparatus.

The following Table I gives the results obtained with the steam jet arranged as an Exhauster for drawing air out of a closed vessel having a capacity of 225 cubic feet. The four last columns show the vacuum produced in the vessel, measured in inches of mercury, when the exhauster had continued in action for the length of time indicated in the first column. The pressure of steam in the boiler was 45 lbs. per square inch, and the sectional area of the annular steam orifice of the jet was varied from 0.05 to 0.20 square inch.

TABLE I.
*Experiments with Steam-Jet Exhauster
exhausting air from a closed vessel.*

Time of action.	Area of annular orifice of Steam Jet.			
	0.05 sq. in.	0.10 sq. in.	0.15 sq. in.	0.20 sq. in.
Minutes.	VACUUM. Inches of Mercury.	VACUUM. Inches of Mercury.	VACUUM. Inches of Mercury.	VACUUM. Inches of Mercury.
1	9	10	$9\frac{1}{4}$	$8\frac{1}{2}$
2	13	$13\frac{1}{2}$	$13\frac{1}{2}$	13
3	$14\frac{1}{2}$	15	$16\frac{1}{4}$	$15\frac{1}{2}$
4	$15\frac{1}{2}$	$15\frac{1}{2}$	$17\frac{1}{4}$	17
5	$15\frac{3}{4}$	$15\frac{7}{8}$	18	$17\frac{3}{4}$
6	$18\frac{1}{2}$	$18\frac{1}{4}$
7	$18\frac{3}{4}$	$18\frac{1}{2}$

Another set of experiments has been tried with the steam jet used as a Blower for compressing air into the same closed vessel of 225 cubic feet capacity. For this purpose the conical delivery funnel of the steam jet was connected with the vessel by means

of a 3 inch pipe containing a stop-cock; and into this pipe was delivered a small jet of cold water through a pipe of $\frac{1}{2}$ inch diameter under a pressure of 40 lbs. per square inch, with the object of condensing the steam from the blower, the water being turned on simultaneously with the starting of the steam jet. The sectional area of the outer annular air passage in the blower was 0.20 square inch, and of the inner air passage in the centre of the jet 0.16 square inch, making a total of 0.36 square inch of air section. The sectional area of the annular steam jet was 0.07 and 0.12 square inch in the different experiments, the results of which are given in the following Table II:—

TABLE II.
*Experiments with Steam-Jet Blower
compressing air into a closed vessel.*

Time of action.	Area of annular orifice of Steam Jet.		
	0.07 sq. in.	0.12 sq. in.	0.07 sq. in.
	<i>With Condensing Water.</i>	<i>With Condensing Water.</i>	<i>Without Condensing Water.</i>
Minutes.	PRESSURE. Inches of Mercury.	PRESSURE. Inches of Mercury.	PRESSURE. Inches of Mercury.
$\frac{1}{2}$	6	5	9
$\frac{2}{3}$	10	9	11
1	12	12	14
$1\frac{1}{2}$	13	16	15
$1\frac{3}{4}$	$13\frac{1}{2}$	19	$15\frac{1}{2}$
2	14	$21\frac{1}{2}$	16
3	15	24	$16\frac{3}{4}$
4	$15\frac{1}{2}$	25	$16\frac{3}{4}$
5	15	$24\frac{1}{2}$	12
6	$14\frac{3}{4}$	$24\frac{1}{4}$	11
7	$14\frac{3}{4}$	$23\frac{3}{4}$	$10\frac{1}{4}$
8	$14\frac{3}{4}$	$23\frac{1}{2}$	10
Final temperature of air in vessel	113° F.	...	158° F

At the end of the fourth minute the stop-cock was closed, shutting off the steam-jet blower, and at the same time the condensing water was shut off; it will be seen that the pressure in the vessel then fell slightly, owing to the condensation of the small residue of the steam from the jet. In the third experiment, in which no condensing water was used, the fall of pressure was more considerable, and the final temperature of the air in the vessel was higher. The steam pressure in the boiler was 50 lbs. per square inch.

The following are some of the applications which have already been made or are in course of being made of this improved form of steam jet.

Pneumatic Despatch Tubes.—First, to the working of Pneumatic Despatch Tubes. For this purpose the steam jet has a great advantage over an ordinary steam engine and air pump in first cost and simplicity, and also in taking up much less space: the latter advantage being of the greatest value when it is required to work pneumatic despatch tubes in crowded localities where it is difficult to obtain room for steam machinery. A pneumatic tube 3 inches in diameter, to be worked on the circuit system arranged by the writer, has been laid down by the postal authorities in London, from the Central Telegraph Station in Telegraph Street to Charing Cross and back, with intermediate stations at the General Post Office and near Temple Bar. The length of tube forming the whole of this circuit is 6890 yards, or nearly four miles. This line was designed to be, and is, as a rule, worked by means of an air pump A, driven by a steam engine, as indicated in the diagram, Fig. 6, Plate 15. The pump draws air out of a vacuum vessel V, and forces it into a pressure vessel P, both vessels being in connection with the pneumatic tube T, as indicated by the arrows. These vessels are introduced in order to prevent the pulsations of the engine from being felt in the working of the tube, and are of course unnecessary when the tube is worked by means of the steam jet. The piston carriers, which are propelled through the tube by the vacuum produced, are of the cylindrical form shown in Figs. 7 to 9, Plate 16; they consist of a gutta-percha case covered

with drugget or felt, and are made an easy fit in the tube, so as to slide freely through it.

This line has been experimentally worked by means of three steam-jet exhausters, similar to the one shown in Fig. 2, arranged in the manner shown at E E E, Fig. 6, so that all three draw air out of the same tube F, the steam being supplied to them by the steam pipe G. When working with these three exhausters, the mean speed of a piston carrier travelling through the tube from Charing Cross to Telegraph Street was $14\frac{1}{3}$ miles per hour. The vacuum maintained in the tube was equivalent to 10 inches of mercury, the steam pressure being 40 lbs. per square inch; and the quantity of coal consumed under the boiler was 56 lbs. per hour. In the case of long lines of pneumatic tubes, it will be better to work them with an exhauster at each end.

For placing the piston carriers into the tube or taking them out of it at the different stations S S, Fig. 6, without interrupting the current of air, the intercepting apparatus shown in Figs. 10 to 12, Plates 16 and 17, is employed. This consists of two short tubes B and C, fixed side by side in a rocking frame, each of which can be brought into line with the circuit tube T at pleasure. Each end of the rocking frame is faced, and works against the faced side of a boss on the end of the circuit tube. Three annular grooves are turned in the faced side of the boss round the end of the circuit tube, for the purpose of preventing the leakage of air between the ends of the rocking frame and the bosses. One of the tubes B in the rocking frame is used as the sending or "through" tube, and is simply a hollow cylinder of the same internal diameter as the circuit tube T; when this is in line with the circuit tube, a carrier can pass through the instrument without being stopped, and this tube is also used for putting carriers into the circuit. The other or receiving tube C has a perforated diaphragm at its down-stream end, so as to arrest the carriers when it is placed in line with the circuit tube, as in Figs. 11 and 12. This receiving tube is D shaped in section, with a flat cover, which can be taken off if required; as for instance, to remove carriers, in the event of two arriving at once and so preventing the

rocking frame from being moved. The flat cover is furnished with a pane of glass, to enable the attendant to see when a carrier has arrived. In order to prevent the continuous flow of air in the whole circuit of tube from being impeded by the receiving tube being left in the circuit after it has caught a carrier, a by-pass F for the air is provided, which communicates with the circuit tube T at both ends of the instrument. A sliding rod H, Fig. 10, held on suitable supports, is supplied for pushing the carriers out of the receiving tube, when intercepted and brought out of the circuit. The manipulation for sending and receiving the carriers is exceedingly simple; and a treadle is provided for moving the rocking frame with the foot.

Raising of Water.—A second application of the improved steam jet is to the Raising of Water. For lifts not exceeding 20 feet a steam-jet exhauster could be used with advantage in situations where the erection of an engine and pumps would be attended with considerable cost and inconvenience, or where the work to be done was of short duration or of an occasional character, such as in draining lands, &c. When employed for this purpose the exhauster would be applied in the manner shown in Fig. 13, Plate 18, where A and B are two closed air-tight chambers fixed at a height of from 16 to 20 feet above the level of the water to be raised; inlet valves C are provided in the bottom of the chambers for the water to enter from the suction pipe D, and outlet valves G for the discharge of the water raised. The exhauster E, supplied with steam by the pipe H, exhausts the air from the chambers A and B through the pipe F, which is provided with a reversing valve L for placing the exhauster in communication with each of the two chambers alternately; and the delivery end of the exhauster, which may be closed by a valve, also communicates with the chambers through the pipe K and the same reversing valve L. The chamber A is provided with a float M, the rod of which works by tappets the tumbling lever N, and this throws over the weighted lever of the reversing valve L by means of the looped rod R.

The action of the apparatus is as follows. While the exhauster is drawing the air out of the chamber B through the pipe F, as shown in Fig. 13, thus causing the water to rise into the chamber through the suction pipe D under the pressure of the atmosphere, the discharged jet of combined steam and air from the exhauster passes through the pipe K into the top of the other chamber A, which is full of water. The water in this chamber will consequently flow out through the bottom outlet valve G, its discharge being aided by the forcing action of the entering current of steam and air from the exhauster; and this forcing action may be regulated by closing the top of the delivery funnel of the exhauster, in which case the discharge pipe for the water from the outlet valve G may be raised above the level of the chamber A. As the water descends in the chamber A, the float M sinking with it moves over the tumbling lever N into the vertical position, from which when the chamber is emptied the lever will fall into the reversed position, thereby throwing over the reversing valve L. The action of the exhauster upon the two chambers is now reversed, the air being exhausted from the emptied chamber A, and the combined jet discharged into the chamber B, which during this time has become filled with water; in this way the two chambers become alternately filled and emptied, and a continuous delivery of water is thus obtained. As the steam contained in the combined jet entering either chamber from the exhauster becomes gradually condensed by contact with the water, a partial vacuum will be already formed in the chamber as soon as emptied, whereby the work to be done by the exhauster in then exhausting the chamber will be diminished. In order to prevent the noise which would be caused by the combined jet of steam and air issuing from the open top of the delivery funnel of the exhauster, a "sound killer" S may be placed on the top of the funnel, consisting of a cylindrical metal vessel containing a series of perforated wooden diaphragms; this contrivance has been found by experiment to be very efficient in preventing noise.

The following are the results of a preliminary experiment made with a rough apparatus for raising water, arranged as shown

in the diagram, Fig. 14, Plate 18. The exhaustor E was connected by a 2 inch pipe F to a closed vessel A capable of holding 10·3 cubic feet, into which the water was raised from varying depths through the suction pipe D of 2 inches diameter. The sectional area of the outer annular air passage in the exhaustor used in this experiment was 0·35 square inch, and of the inner air passage in the centre of the jet 0·16 square inch, giving a total of 0·51 square inch of air section. With the sectional area of the annular steam orifice adjusted to 0·09 square inch, and with a steam pressure of 60 lbs. per square inch in the boiler, the exhaustor raised 10·3 cubic feet of water 12 feet high in 40 seconds, and the same quantity 17½ feet high in 75 seconds. With the same area of air section, but with the area of the steam orifice adjusted to 0·08 square inch, and with 50 lbs. steam in the boiler, 10·3 cubic feet of water were raised 15 feet high in 40 seconds. The height of lift attainable depends upon the pressure of steam employed; and the quantity of water raised depends within certain limits upon the magnitude of the jet.

Evaporation of Sugar.—A third application of the improved steam jet is to the Evaporation of Sugar. In consequence of the remarkable results obtained with this steam-jet exhaustor, it is proposed by Mr. R. A. Robertson of London to apply it to sugar boiling in the West Indies; and he has communicated to the writer the following notes on the subject.

The steam-jet exhaustor has been employed experimentally with considerable success in exhausting vessels for evaporating liquids in vacuo, and its application for this purpose promises to become of great value in the colonies for evaporating cane juice, principally on account of the simplicity of the arrangement. The great loss and deterioration consequent on the high temperature to which cane juice must be exposed for evaporating it on the old system in open pans are well known, and many ingenious pans have been invented and to some extent worked for evaporating at low temperatures; but, on account of the improved pans being either very much more costly or requiring much more skilled attention

to work them, the greater part of the sugar produced is still made on the old and wasteful plan. Of all the contrivances for evaporating at low temperatures the ordinary vacuum pan exhausted by pumps is at present the best, when carefully designed; and in it under favourable circumstances very rapid evaporation can be produced at low temperatures. In the sugar-growing colonies however almost every circumstance is unfavourable for this mode of working; the water required for condensing the vapour from the evaporating pan is warm, and consequently must be used in large quantities, thereby necessitating large pumps for its removal, and for exhausting the pan; the pumps and motive power thus form together with the pan a very costly apparatus, which requires a considerable amount of skilled attention, often not obtainable, and frequent repairs.

On the contrary, a vacuum pan exhausted by the steam-jet exhauster in the manner shown in Figs. 15 and 16, Plate 19, becomes a very simple apparatus, only requiring a supply of steam at a moderate pressure for the jet A, which exhausts the vapour given off by the boiling solution of sugar or other liquid in the pan B; and the steam and vapour together are then passed through the heating tubes D of the pan, thereby producing evaporation. The area of the steam jet is regulated by the hand wheel C, the steam being supplied by the pipe E; and the course of the current of steam and vapour is indicated by the arrows. By this arrangement the costly vacuum pumps and the steam engine or other motive power are dispensed with, as well as the condenser and its supply of condensing water, the latter being in many places a consideration of vital importance; and in their stead is substituted the steam-jet exhauster, a comparatively cheap and simple apparatus, requiring little or no attention, and not liable to get out of order.

Experiments on this mode of evaporating have been so successful that a vacuum pan is now being constructed as above described, capable of evaporating 50 cubic feet of water per hour, in which it is estimated that a vacuum of from 18 to 20 inches of mercury will be maintained. The form of pan shown in Fig. 16 is the simplest arrangement in which the steam-jet exhauster can be applied for

the purpose; but the exhauster can with equal advantage be applied in those cases where vacuum pans are worked on the systems known as double and triple effect. It has been successfully employed to exhaust a vacuum pan having a condenser placed high enough above the ground to discharge by gravitation against the vacuum the condensing water in which the vapour from the pan was condensed; there was thus left only the air and a very small quantity of vapour to be removed by the exhauster, which in this case was a very small one, not using sufficient steam to produce evaporation.

The steam-jet exhauster is further expected, on account of its cheapness and simplicity, to prove very useful in the colonies for draining the molasses from the sugar, by exhausting the air from below the perforated bottom of a strainer containing the undrained sugar, the pressure of the atmosphere then driving the syrup or molasses through the sugar and perforated bottom. By this means the crude and imperfect mode of draining by gravitation, and also the more elaborate but costly and troublesome centrifugal strainers, can be superseded with advantage.

Blower for Gas Producers.—A further application of the improved steam jet is to Gas Producers for heating purposes. The author has had occasion to make numerous applications of the steam jet arranged as a blower for accelerating the distillation of fuel in his gas producers, as shown in Figs. 17 and 18, Plate 20.

The blower B is built into the side wall of the producer, and the combined current of air and steam delivered by it issues through an opening A into the space C underneath the firegrate, which is closed by doors D. The small proportion of steam that enters together with the air is just sufficient to assist beneficially in the production of the combustible gas, inasmuch as in passing through the incandescent fuel the steam becomes converted into hydrogen and carbonic oxide. The steam is admitted to the blower through the branch pipe E from the main steam pipe F, which supplies a number of blowers in a series of gas producers. A valve G is provided in the branch pipe E, for shutting off the steam from the

blower when not in use; and a small tap J serves for discharging any water that may collect in the pipe by condensation of the steam.

The advantages found to result from applying these blowers to gas producers are, that coal dust of the most inferior description can be used, and that the gas production of each producer in consuming small fuel is raised from $1\frac{1}{2}$ tons to 3 tons of gas per 24 hours; while at the same time the quality of the gas is improved, owing to the generation of hydrogen from the steam, which enters intermingled with the air.

These applications of the improved steam jet suffice to illustrate its scope and value. Other useful applications will readily suggest themselves, where work may be accomplished by exhausting or compressing air or gases.

In conclusion the author would remark that although the steam jet is not a new mechanical agent, and has been applied before for various purposes and in a variety of forms, yet the mechanical conditions under which it is capable of developing the greatest amount of useful effect have not previously been laid down or practically realised in such a way as to produce results at all comparable with those obtained from a steam engine working an air pump; but this it is maintained a steam jet may do, if care be taken that the available elastic force is changed into onward motion of the combined jet, and again into onward pressure, without undue loss of effect by eddies or by development of sound or heat, which have constituted the principal results in the case of an ordinary steam jet.

The PRESIDENT said he had been led to investigate the subject of the steam jet in consequence of having been engaged in constructing a circuit of pneumatic despatch tube for the Central telegraph office in London; the tube itself had cost £3000, and fully as much had

been spent on the engine and air pump. As there was moreover great difficulty in finding room for this machinery in so crowded a locality, it had occurred to him that a more direct means of propelling the piston carriers through the tube would be a matter of some importance; and in considering the conditions of a steam jet he had been led to the conclusion that, if the elastic force of the steam could be all employed for giving velocity to its particles, and if each particle of steam so accelerated could be brought into direct and immediate contact with the air to be impelled, an average speed of the combined current could be obtained, which should represent nearly the whole of the elastic force originally existing in the steam. If this combined current were then sent through a long expanding mouthpiece or tube, enlarging gradually in a parabolic curve, so that the velocity of the current should be gradually converted into pressure by bringing the particles nearly to rest, it had appeared to him that very favourable results might be obtained; and the experiments he had made had proved that these anticipations had been correct.

There were some remarkable results connected with this steam jet. The quantity of work done by it, measured by the weight of air delivered per minute, was proportionate absolutely to the amount of surface contact between the steam jet and the air to be impelled, irrespective of the pressure of steam employed. Thus in discharging the combined current into the atmosphere, the same weight of air per minute would be thrown out with a steam pressure of 5 lbs. as with 60 lbs., the only difference being that with the lower pressure of steam the limit of exhaustion or compression would be sooner reached than with the higher. The experiments also showed that the degree of exhaustion or compression capable of being produced by the steam jet, that is the difference of pressure between the air at the jet and that in the vessel from which the jet was exhausting or into which it was compressing the air, was exactly proportionate to the steam pressure; so that with 100 lbs. steam above the atmosphere the degree of exhaustion or compression attainable was double what it was with 50 lbs. steam. A third result was that, in exhausting the

air from any vessel by the steam jet, it took as long a period of time to exhaust the first 1 lb. of pressure, from the atmospheric pressure of say 15 lbs. down to 14 lbs., as it did to reduce the pressure 1 lb. in any lower part of the scale, say from 8 lbs. to 7 lbs.; this was explained by the consideration that the weight of air, which had to be put into motion with such a velocity as would force it through the contracted opening at the base of the expanding delivery tube, was the measure of the working capacity of the instrument. These were very distinctly marked characteristics of a good steam jet; and if they were attended to in the construction of the jet apparatus for any particular application, it would be found that very economical results could be realised for the steam expended.

He exhibited a full-size specimen of one of the steam-jet exhausters employed to exhaust the pneumatic tube connecting the telegraph offices in London, so as to maintain a current of air flowing continuously through the tube in the same direction. The tube formed a complete circuit, and the piston carriers, whether put in at the commencing station of the circuit or at any intermediate station, all travelled in the same direction; the result was that a tube of only 3 inches diameter was sufficient for a great amount of work, because there might be ten or more carriers in the tube at a time, all flowing towards the end station, but capable of being intercepted and taken out at any intermediate station.

Mr. L. OLRICK enquired whether in the use of the steam jet the parabolic form of the delivery tube was found to make much difference in the efficiency of the instrument, in comparison with a parallel tube or an ordinary cone with straight sides. He understood that in the early experiments upon the ejector condenser the expanding discharge tube for the delivery of the water had been found to produce a greatly increased effect, as compared with the parallel tube originally tried. He asked also whether the mixing chamber in the steam-jet apparatus was shaped to the form of the "vena contracta," from the orifice of the jet to the base of the delivery tube; and what difference was produced by the shape of the air entrance, according as it

was tapered before reaching the jet orifice or made parallel right up to the jet. It appeared to him that this improved steam jet would be applicable to a variety of purposes, and that one application might be to the blast-pipe in locomotives. On some railways the locomotives were made with conical chimneys expanding upwards, which he understood were found to render the blast more effective, and cause less back pressure in the cylinders, than was the case with the usual parallel chimneys; and he thought that the efficiency of ordinary boilers, where the exhaust steam was used as a blast for creating a draught, might be very materially increased, and a saving of fuel effected, with scarcely any back pressure in the cylinders, if due attention were paid to the results derived from the careful experiments which had been made in connection with the very perfect steam jet now described.

The PRESIDENT replied that the expanding form of the delivery tube from the steam jet was of considerable importance, though not so much so in the case of air as where a denser fluid had to be dealt with, as in the water jet of the Giffard injector. From experiments that he had made with a parallel delivery tube, in comparison with the expanding form, he had found that, in exhausting a vessel to the extent of producing a vacuum of 20 inches of mercury, the expanding tube rendered the jet about ten per cent. more effective than it was with the parallel tube; but in exhausting to only a small extent, the greater density of the fluid would cause the expanding tube to be as much as twenty per cent. more effective than a parallel one. The form which he had adopted for the expanding delivery tube of the steam jet was a parabolic curve; but the difference in effect between this and an ordinary straight cone, with the same areas of passage at the two extremities, would be immaterial. The mixing chamber, which had to be of a definite length in proportion to the breadth of the annular air passage, was made to diminish gradually in area, somewhat in the form of a "vena contracta," the rate and extent of contraction being determined in each individual case according to the velocity of the combined issuing current. But the point of chief importance in the instrument was the mode of bringing the entering air into

contact with the steam jet. As the working power of the jet was proportionate to the extent of surface contact between the steam and the air, the annular form of jet suggested itself as the most suitable; and the thickness of the annular film of steam should be very small, about 1-50th inch having been found by experiment to be the maximum thickness of film that was consistent with economical results. If the thickness of the jet were increased beyond this amount, the particles of steam inside the thickness of the jet would flow on at a greater rate than the outer particles forming the skin of the jet, the latter being retarded by contact with the air; and eddies within the atmosphere of the steam itself would be the result. Again, if the steam jet were simply made to issue into a plain open tube, through which the air had to be propelled, the result would be very inconsiderable, because the eddies formed between the air and the steam would then attain their maximum amount; the steam issuing with great velocity and the air being nearly stationary, the latter would not be so much impelled in a steady current as set in rotation and rolled forwards by the power represented by the difference of velocity between the two fluids. It was consequently requisite that the air should be accelerated as nearly to the full velocity as practicable before coming into actual contact with the steam; and this was the most important point connected with the apparatus. The area of the air passages was therefore gradually contracted for some distance as they approached the issuing orifices; and the combined areas of the central air aperture inside the steam jet and of the annular aperture outside the jet were made to be together rather less than the area of the issuing orifice at the outer extremity of the mixing chamber, through which the combined current issued; this arrangement ensured the air attaining the full velocity of the combined jet, whereby the amount of eddies and the consequent loss of power were reduced to a minimum.

Mr. J. B. FENBY enquired what had been found to be the relative expenditure of steam in the jet, when employed in producing a vacuum, for effecting an equal reduction in the pressure of the air at different degrees of vacuum. The length of time required to

reduce the pressure 1 lb. had been stated to be the same, whether the reduction were from 15 to 14 lbs. or from 8 to 7 lbs. ; but it appeared to him that the amount of work done in the latter case would be greater than in the former, because with the greater vacuum in the exhausted vessel the same weight of air had to be discharged against the greater excess of pressure of the external atmosphere : just as, in the case of an engine working an air pump, the load on the engine would increase in proportion to the degree of vacuum already produced by the pump. One application that occurred to him, for which the steam jet would probably be advantageous, was the air blast for millstones, for removing the stive or dust from the casing of the stones during the grinding. From the small space occupied by the instrument, and the great velocity produced in the current of air, it seemed to him likely to be well suited for that purpose, particularly if employed for exhausting the air, its efficiency being greater in exhausting than in compressing ; and he thought it would probably be more suitable than the blowing fan used for ventilating millstones.

The PRESIDENT replied that that application of the steam jet might be attended with good results ; but it must be observed that the jet acted at a disadvantage when producing only a small degree of exhaustion or compression, though this disadvantage might to a certain extent be obviated by reducing the area of the jet orifice when the work was below the capabilities of the full jet. For as the surface of contact between the steam and air determined the work done, and the quantity of steam of a given pressure in the jet in proportion to the air determined the degree of vacuum or compression produced, it followed that, in order to work economically, the area of the steam orifice ought to increase gradually as the vacuum or compression increased. Under any circumstances however the jet would be to some extent less advantageous when producing only a small degree of vacuum, because the difference of velocity between the steam and the air, which was productive of eddies, was then greater than when an equal weight of air was discharged from a higher degree of vacuum, a larger proportion of the velocity of the steam being utilised in the latter case for

overcoming the greater excess of pressure of the external atmosphere. The steam jet had not yet been applied for producing the air blast for millstones, but no doubt it might be employed advantageously for that purpose.

Mr. J. ROBINSON, who occupied the Chair during the discussion of the President's paper, remarked that several attempts had previously been made to take advantage of the induced currents created by a steam jet. In the early application of the blast pipe in locomotive engines, when the blast had not been sufficiently effective in producing the draught required for the fire, he remembered one improvement introduced had been what was known as the "petticoat" blast pipe, consisting of a succession of cones arranged one above another with a set of concurrent lateral openings between, the object being to equalise the force of the draught throughout the height of the smokebox, instead of producing a strong draught through the upper tubes and a weak one through the bottom tubes, as was the case when the blast pipe was carried up solid to the top of the smokebox, causing the steam jet to act upon the air only at that point; the larger area of the improved blast pipe had also occasioned a diminution of the back pressure in the cylinders. A similar improvement had been tried on the Giffard injector, by inserting a number of conical nozzles, one behind another, so that a smaller quantity of water should be brought into contact with the jet at each successive step, instead of the steam jet having to encounter all the water at once, the effect of the cones thus being to increase the extent of surface contact between the steam and water. A jet of steam had also been applied for inducing a current of air as a blast for cupolas employed for melting iron; instead of forcing the air into the bottom of the cupola by a blowing fan, the closed top of the cupola was exhausted by a steam jet in the chimney, by which means the air was drawn in uniformly through openings made all round the bottom of the cupola. With regard to the application of the steam jet for raising water, the method described in the paper presented a marked contrast to that attempted in Giffard's first trials for the purpose, where the steam had simply been turned direct into the stationary water at the bottom of the ascending pipe through

which it had to be raised ; and in consequence of the inertia of the water and the fact that the whole mass of water had to be started into motion at the jet, there had necessarily been a great loss of effect by the production of eddies, instead of an even flow. The plan now described seemed much the more philosophical and advantageous, in which the steam jet was not brought to bear direct upon the water, but was applied to exhaust the air from a closed vessel, and the water was then raised into the vessel by the pressure of the external atmosphere ; because the steam would more readily carry off the air from such a vessel into the atmosphere than it would put into motion a column of water, the inertia of the water being so greatly in excess of that of air. One valuable application of the steam jet that occurred to him would be to the ventilation of the cabins and stoke-holes of ships, particularly in the case of ironclads, where the admission of air was rendered so much more difficult by the absence of openings in the sides of the ship. It had indeed been attempted to use a blowing fan for introducing a supply of fresh air in such cases ; but he considered a much better plan would be to exhaust the bad air, and leave the fresh air to find its way in wherever it could ; and for this purpose the steam-jet apparatus now described appeared most suitable, and he should be very glad to hear of its being so applied. There were also without doubt many other directions in which the improved steam jet might be usefully employed with advantage.

He moved a vote of thanks to the President for his paper, which was passed.

The Meeting then terminated.

STEAM JET.

Plate 13.

Steam - Jet Exhauster or Blower.

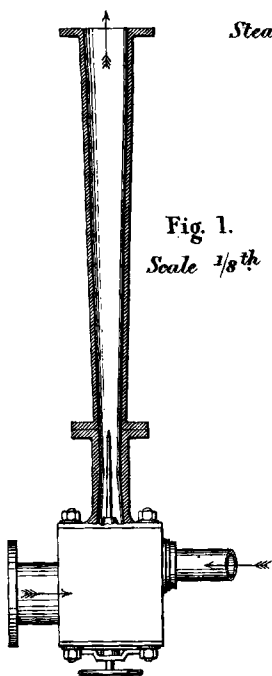


Fig. 1.
Scale $\frac{1}{8}$ th

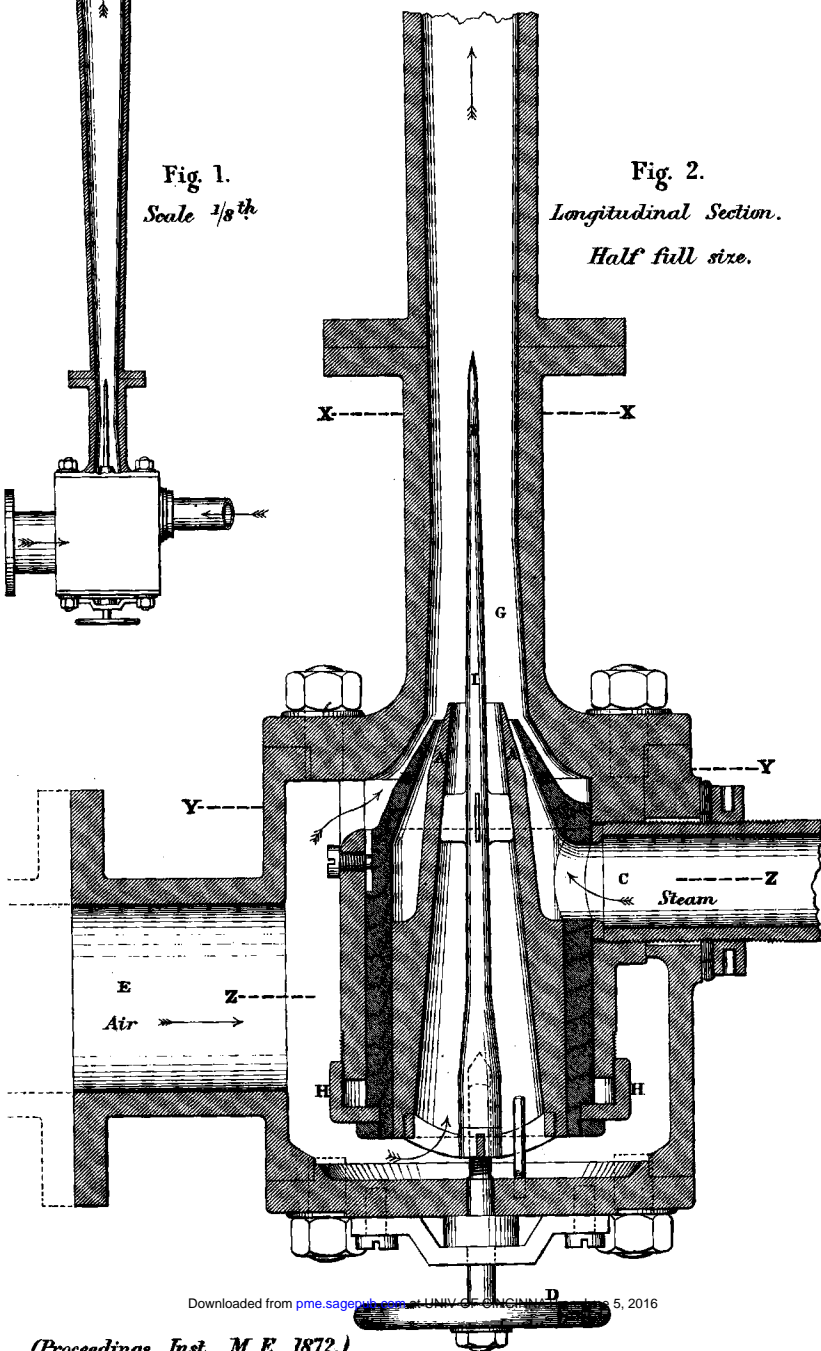


Fig. 2.
Longitudinal Section.
Half full size.

Steam - Jet Exhauster or Blower.

Fig. 3. Transverse Section at XX.

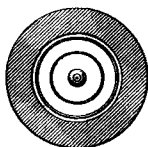


Fig. 4. Transverse Section at YY.

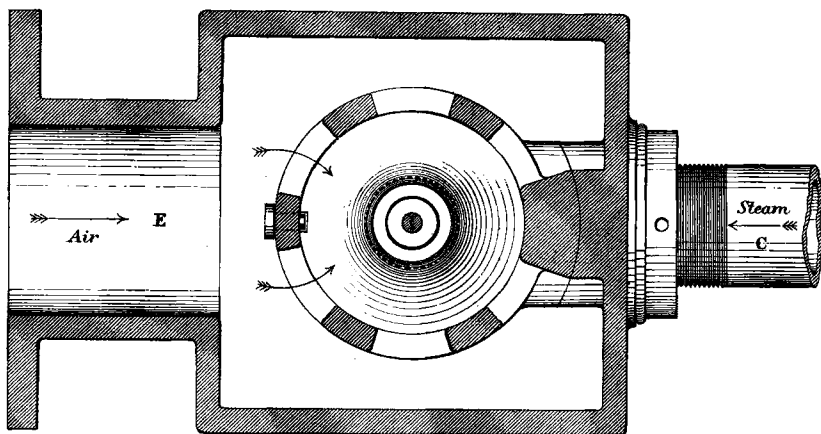
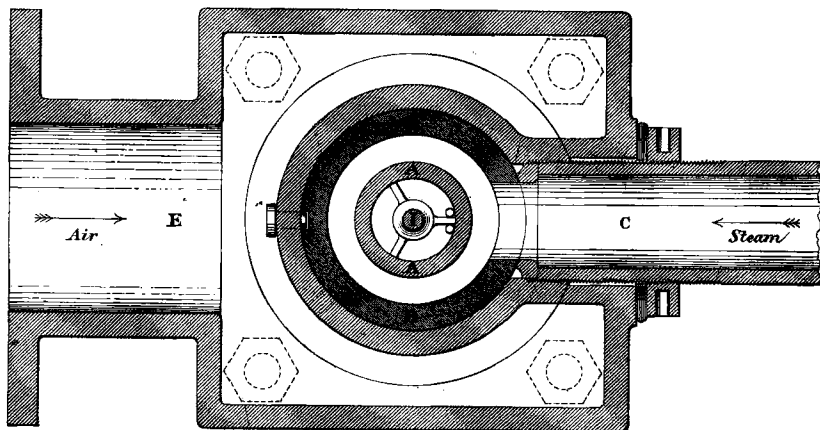


Fig. 5. Transverse Section at ZZ.



STEAM JET.

Plate 15.

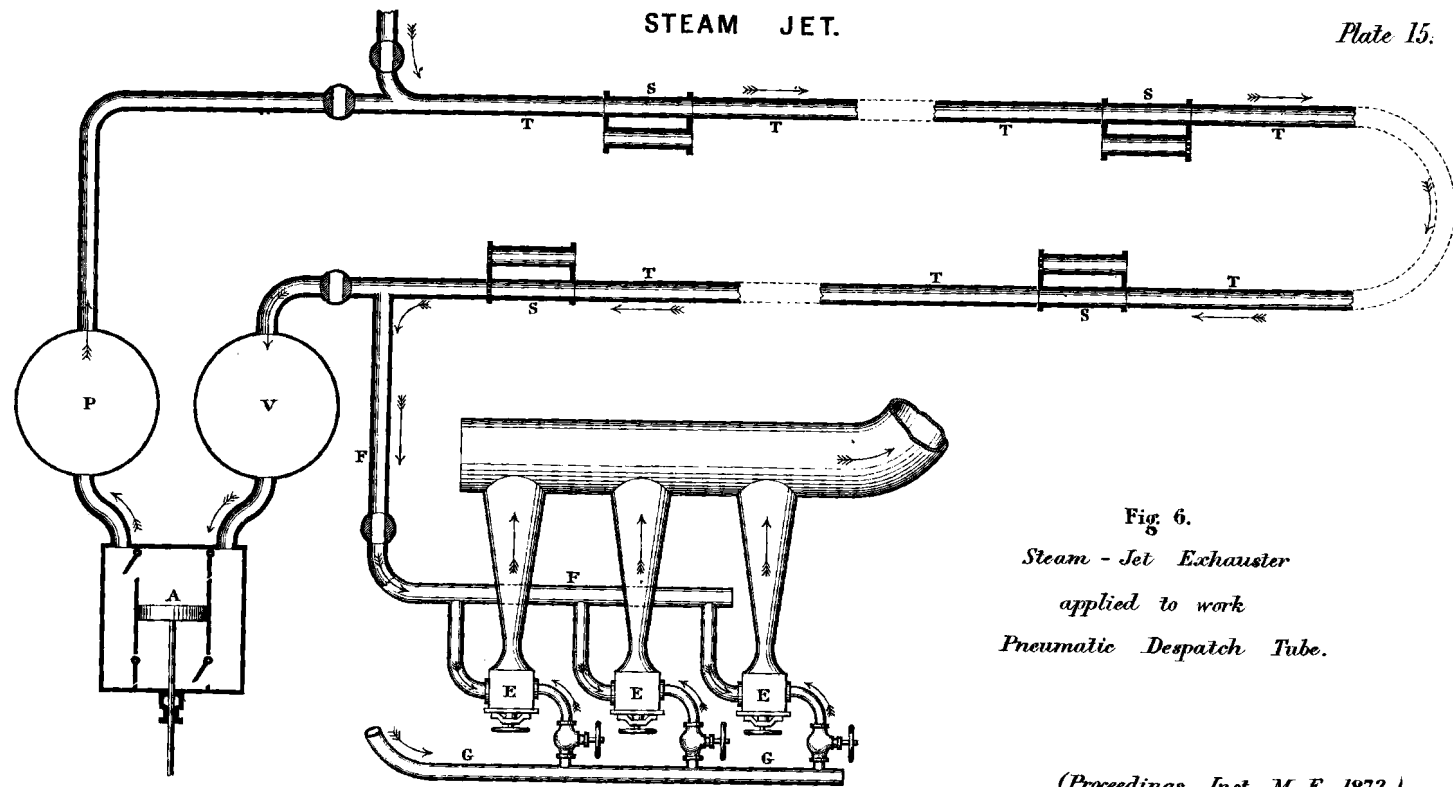


Fig. 6.

*Steam - Jet Exhauster
applied to work
Pneumatic Despatch Tube.*

(Proceedings Inst. M. E. 1872.)

STEAM JET.

Plate 16.

Pneumatic Despatch Tube.

Piston Carrier travelling through tube.

Fig. 7. *Side Elevation.*



Fig. 8. *Transverse Section.*

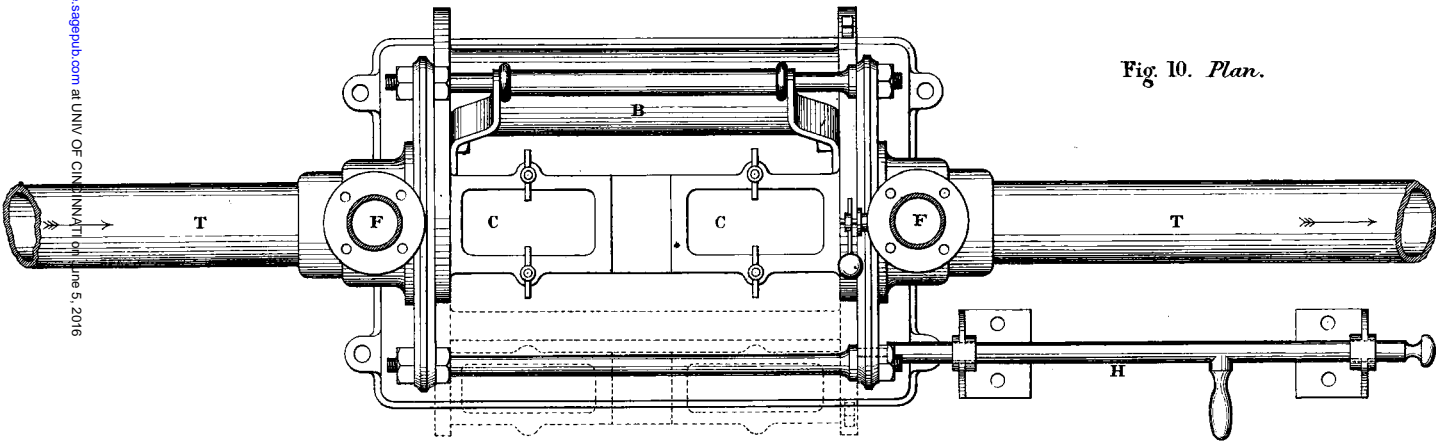


Fig. 9. *Longitudinal Section.*



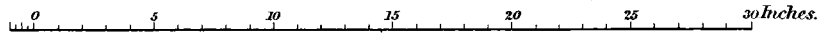
Intercepting Apparatus at Stations.

Fig. 10. *Plan.*



(Proceedings Inst. M. E. 1872.)

Scale $\frac{1}{8}$ "



STEAM JET.

Plate 17.

*Pneumatic Despatch Tube.
Intercepting Apparatus at Stations.*

Fig. 11. *Transverse Section.*

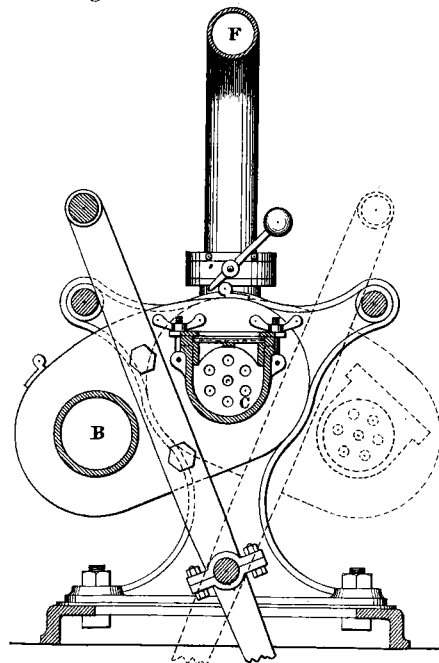
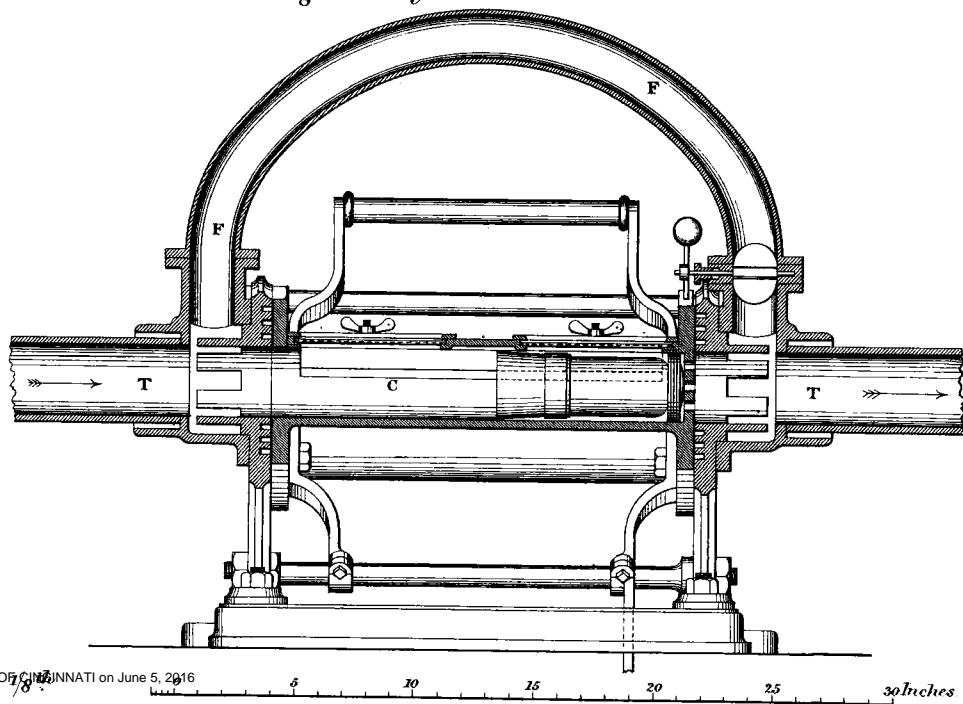


Fig. 12. *Longitudinal Section.*



STEAM JET.

Plate 18.

Fig. 13. *Steam-Jet Exhauster applied to raise Water.*

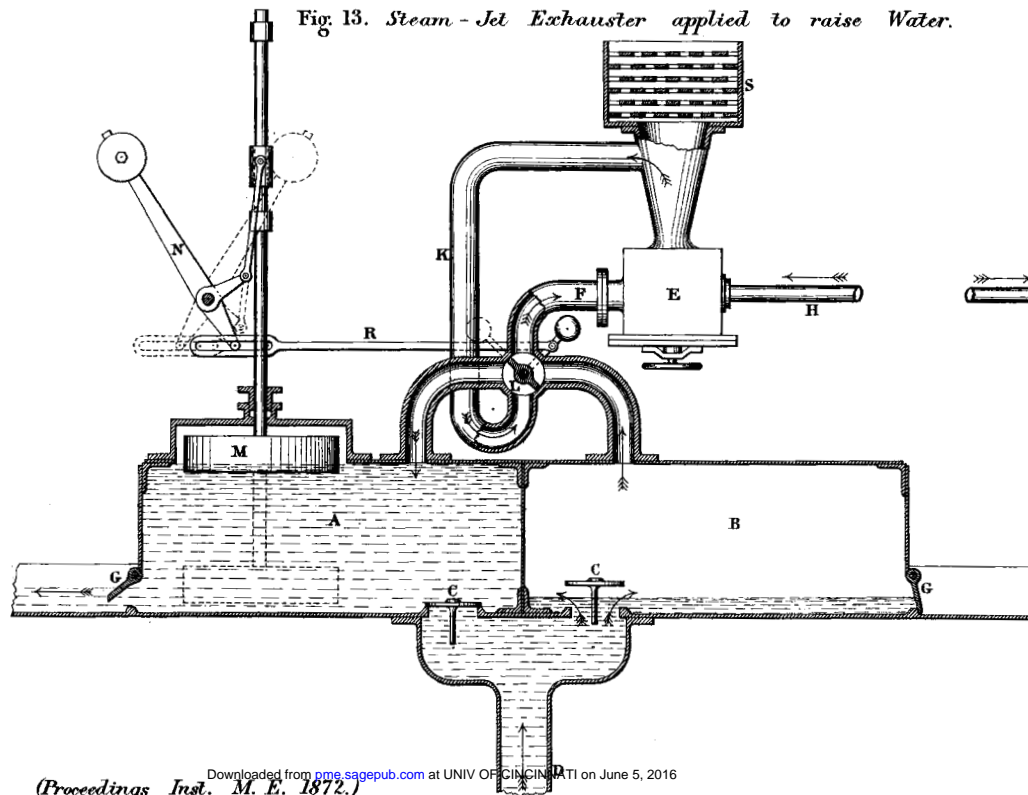
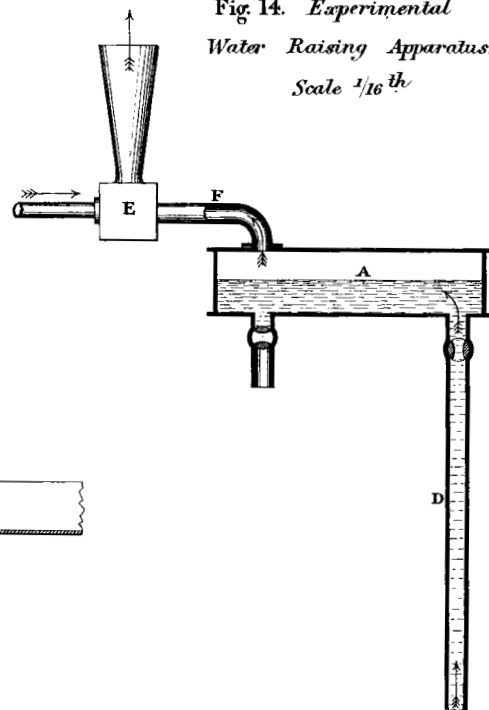


Fig. 14. *Experimental Water Raising Apparatus.*
Scale $\frac{1}{16}$ in.



STEAM JET.

Plate 19.

Steam - Jet Exhauster applied to Sugar Evaporating Pan.

Fig. 15. *End Elevation.*

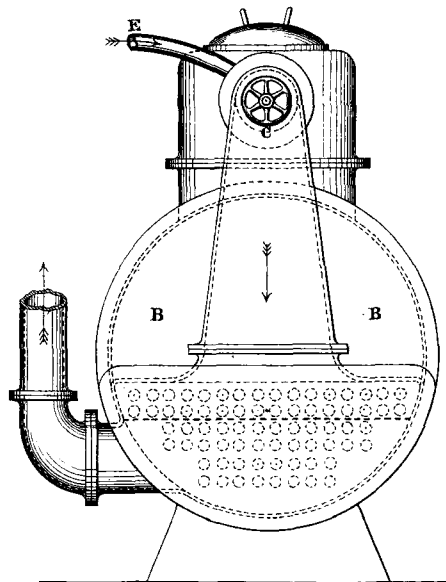
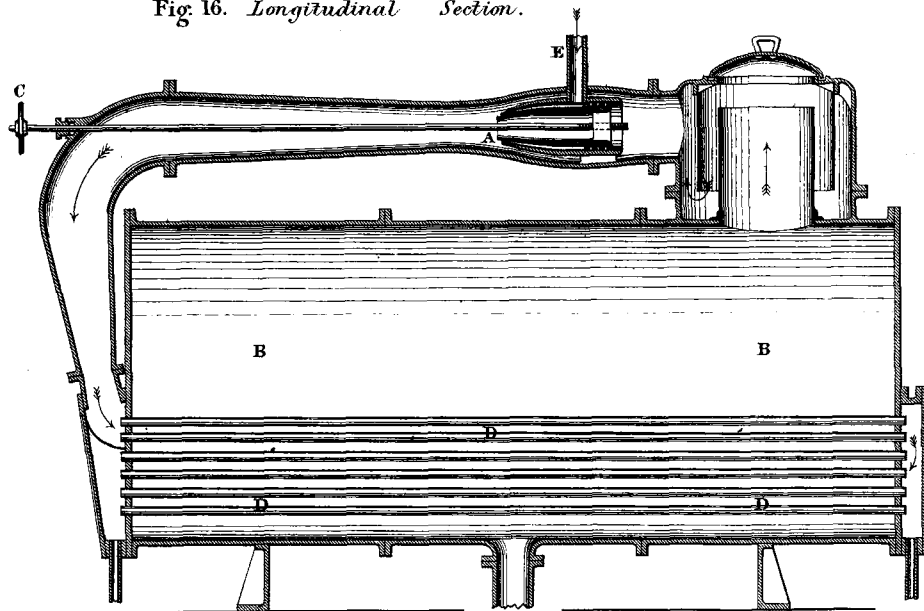


Fig. 16. *Longitudinal Section.*



(*Proceedings Inst. M. E. 1872.*) Scale $\frac{1}{36}$ th Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Fig. 17. *Steam-Jet Blower*
applied to Gas Producer.
Scale $\frac{1}{30}^{th}$

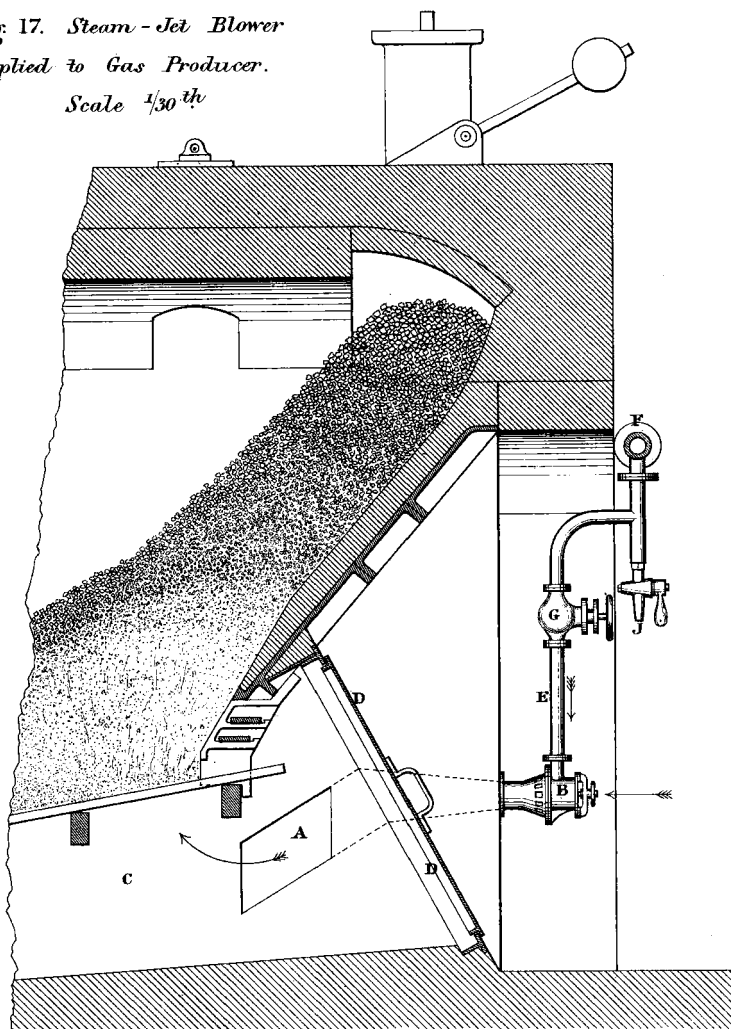


Fig. 18. *Longitudinal Section of Blower.*
Scale $\frac{1}{10}^{th}$

