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JOHN ROBINSON M'CLEAN, President,
in the Chair.

No. 1,128.—“Giffard's Injector.”¹ By JOHN ENGLAND,
M. Inst. C.E.

BEFORE entering into the description of this instrument, it may not be uninteresting to glance at what is recorded to have been done by others, for raising or forcing water by means of a jet of steam and apparatus without moving parts.

In 1684, Solomon de Caus, an Engineer and Architect to Louis XIII. of France, raised a jet of hot water by means of a vertical tube which, passing through the top, reached nearly to the bottom of a closed vessel, and the pressure of the steam on the surface of the water therein contained.

In a patent, granted by Charles I., in 1630, to David Ramseye, is claimed, among other things, ‘the raising water from low places, mynes and coal-pits, by fire,’ the word steam not being then in use.

In 1663, the Marquis of Worcester, in his “Century of Inventions,” describes a way to drive up water by fire, not by drawing or sucking it upwards, but by making vessels, the one to fill after the other, so that the water runs like a constant fountain-stream, 40 feet high. One vessel of water rarified by fire driveth up forty of cold water, and one vessel of water being consumed, by turning two cocks, another vessel begins to force and refill with cold water, and so successively.

This apparatus appears to have been fixed at or below the level of the water to be raised, and, as the Marquis does not seem to have been aware of the effect of steam condensation, must have been very simple; the vessels being filled, their contents were projected upwards by the impulse alone of the steam.

Savery, in 1698, fixed his apparatus about 2 feet below the height representing the pressure of the atmosphere above the level of the water to be raised. The steam which filled his vessel was condensed from the outside; the water which filled the vacuum thus obtained, was further raised by the quantity of motion in steam, as in the system of the Marquis.

¹ The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

In 1818, the Marquis de Manoury d'Ectot, who appears to have been the French prototype of the Marquis of Worcester, took out a 'brevet d'invention' for the drawing in and carrying up any fluid by means of a steam jet. In his 'Century of Inventions,' the Sieur Manoury, as he was styled in those republican days, gives a description of an apparatus 'to draw up water from a pit, not only from the depth where it would equilibrate the atmosphere, but from a much greater.' The steam-chamber he fixed at the height to which the water was to be raised; condensation being effected inside this chamber by a jet of water from a contiguous cistern; a column of water, previously supplied from this cistern, would now be sustained at a height due to the atmospheric pressure. At this height the suction-pipe was enlarged by a spherical water-chamber, passing through which, and terminating a little above it, a tube from the cistern conveyed a jet, whose force of projection, converted into pressure, overcame the quiescent force of the column of water which, already supplied from the cistern, filled the continuation of the suction-pipe, whose transversal area gradually increased till its junction with the steam-chamber above. Now, the jet from the cistern, by transmission of its quantity of motion to a proportional quantity of water raised successively from the pit to the water-chamber, by atmospheric pressure, carried that quantity to the steam-chamber which, when filled by this confluence, discharged into the cistern, whence a quantity, equal to that drawn from the pit, flowed to its destination.

It will thus be seen, that when Manoury, by the same means as Savery, had raised water to the height due to atmospheric pressure, instead of, like Savery, carrying it further by means of a steam-jet, he employed a water-jet for raising it to the required height; so that Savery's method, though more than a century older than Manoury's, approaches nearer to that about to be described.

THE MECHANISM OF THE INJECTOR.

It is proposed to divide the apparatus into two distinct parts, defined by an imaginary plane passing at right angles to the axis of the instrument, through the space S_1 , Plate 11, Fig. 1.

1°. The part above this plane is an adjutage, through which the jet of mixed steam and water is forced by the pressure from the boiler.

2°. That below the plane represents the adjutage which receives the mixture of steam and water for transmission to the boiler.

Of these two parts, the first consists of an inner tube I, sliding in a cylinder O, and dividing it into two chambers, the one S, for the steam, the other, W, for the feed-water. To the cylinder O

is fixed a convergent tube L, which throughout this Paper will be called the 'lance,' within which, but less convergent, the termination of the inner tube I is slid and withdrawn to the extent required, by the handle and screw N, carrying a divided plate. In the inner tube, whose tapering part T is called the tuyère, a solid plug, called the needle, with a tapering termination, increases or diminishes the steam-passage by its less or greater extent of insertion.

The steam from the boiler being admitted to the chamber S, thence passes by holes to the inner tube, whence, by means of the screw N, a slight withdrawal of the needle lets it in to the 'lance.'

In this state of things, the steam-jet would pass through the 'lance' and be lost in the atmosphere; but if the tuyère, by the action of the screw W, be withdrawn from the 'lance,' an annular jet of water from the chamber S will enter the 'lance' and be carried forward or drawn in by the action of the steam-jet from the tuyère, in such wise, that a column made up of steam condensed and non-condensed and liquid water, henceforth called the 'sheaf,' will be formed and projected, in the direction of the axis of the instrument, through the terminus of the 'lance.'

The withdrawal, then, of the inner tube from the 'lance' forms an annular space, determining the quantity of feed-water according to its temperature and the boiler-pressure; the higher the pressure, the greater the opening required; so that, between the point where the tuyère closes the 'lance,' and the opening corresponding to the greatest steam-pressure, is the traverse of this adjutage comprised.

For condensing-engines, a small self-acting valve placed at the orifice of the overflow-pipe, which shuts as soon as the work of injection is established, prevents any air being drawn in by the sheaf into the boiler, and thence into the condenser.

In the axis of the 'lance,' at a short distance from its end, is fixed the second part of the instrument, consisting simply of a divergent tube leading directly to the boiler, and furnished with a valve, which, when the work is stopped, closes with the back-pressure.

The modification introduced into the first part of the apparatus (Fig. 1) is represented in Fig. 2, and has been supplied for a stationary boiler, which, at 60 lbs. per square inch pressure, is of 240 nominal, or 480 actual horse-power.

1°. It will be observed that the tuyère, instead of sliding with the inner tube I, is fixed to the cylinder O, so that it becomes the terminus of the steam-pipe from the boiler.

2°. The inner tube I, instead of carrying the needle, contains the 'lance' L and the divergent tube, and is now, when moved

towards the fixed tuyère, the water adjustment; in this wise, the packing between the water and steam-chambers, which with the moving tuyère was needed, is dispensed with.

Fig. 3 represents a modification of Fig. 2. Whatever be the apparatus used, says the author (M. Turck) of this modification, it is well known that the warmer the water the less the indraught thereof; for, as soon as a partial vacuum is produced, the water thereby vaporises, and as the temperature is increased does vaporisation tend to fill up the vacuum.

The inner tube I in this arrangement isolates the water-chamber. In setting to work, the withdrawal of the needle producing an annular steam passage of only one 50th of an inch wide, the effect of this isolation must be very perceptible, for if, on the contrary, the condensing feed-water comes in contact with the tuyère, some of the steam, passing through a passage so narrow, must be condensed, rendering the in-draught at low pressure liable to suspension.

Moreover, the inner tube I, instead of carrying the 'lance' and the divergent tube, as in the first modification, moves independently of them, as well as of the needle; and thus, not only dispenses with the packing between the water and steam-chambers in the original instrument, but gets rid of packing altogether.

In the original instrument (Fig. 1), should the packing be imperfect, in addition to the contact of the condensing water with the tuyère, not only will the in-draught be difficult to effect, but it will also be difficult to avoid waste of steam at starting, and to vary the feed, while the least change in the steam-pressure, or in the other conditions of working, will throw the apparatus out of gear. In this wise the hesitations or caprices remarked in starting to work the first injectors may be accounted for.

THE 'LANCE.'

The form of this adjutage has been determined principally by experiment. Theoretically, the section of its orifice should be the same as that of the minimum section of the divergent tube with which it might be merged; but to facilitate the starting to work, they have been separated, and an excess given to the orifice of the 'lance' for the passage of a certain quantity of uncondensed steam or aqueous vapour.

The 'sheaf,' notwithstanding this quantity of aqueous vapour, does not fill this orifice, taking no more than the $\frac{1}{(1.3)^2}$ part, at the maximum feed, and at the minimum feed, does not even fill the entrance of the divergent tube which it passes, in virtue of its inferior density, with a velocity greater than that with which

an opposing column of water would, if unopposed, flow from the boiler.

The minimum section of the divergent tube is the unit by which the other parts of the instrument are measured and proportioned, and determines its power of injection.

Experiments have given 1·3 for the orifice of the 'lance' which is nearly that of the tuyère, nevertheless, at very high pressures this must be reduced to 1, the tuyère then being 1·2.

THE DIVERGENT TUBE.

The inventor was of opinion that the form of this adjutage might be modified in many ways, provided always that for a certain length from the minimum section or throat the taper be very slight; but he did not, when he described this part of the instrument, anticipate holding the same opinion, and verifying the same thing, as M. Turck; that no modification of its form, beginning with a length of 60 times and ending with exactly the diameter of the throat, *i. e.*, cutting this tube off close to the throat, has any influence whatever; for M. Giffard's own words were, in speaking of the actual energy of the sheaf, "*cette force vive se transforme en travail mécanique dans l'intérieur du tube-divergent*;" and, again, he says, "*la pression effective du jet va en croissant depuis l'entrée jusqu'au gros diamètre du tube-divergent*."

THE 'SHEAF.'

Quantity of motion being quantity of matter incorporated with space passed over in unit of time, the 'sheaf' has, for each time-unit the same quantity of motion as the steam-jet had on issuing from the tuyère; since its quantity of motion is the dynamic equivalent of the pressure which produced it.

Let the minimum section of the divergent tube be equal in area to that of the tuyère, from both of which let water issue under the same pressure which ejected the steam; then, each water-jet has the same quantity of motion for each time-unit as the steam-jet, likewise as the 'sheaf' had; and any two of the three liquid-jets, encountering each the other, equilibrate. In other words, if the orifices of the steam and feed-pipes be of the same diameter, and water, under the same pressure which gave the 'sheaf' its force of projection, issues from both of them; then it is as clear that either one of these liquid-jets would, if opposed to, neutralize the 'sheaf,' as it is that the two neutralize one another. But, make the orifice of the tuyère the larger of the two, the steam-jet issuing therefrom being, by condensation, reduced to the section of the smaller, is then, in the same ratio, the stronger; since it has the quantity of

motion due to the larger area of pressure; and, therefore, at any rate with an intermittent action, drives back the water-jet which tends to issue from the throat of the divergent tube.

The indraught of the feed water is accounted for in the same manner as the working of a forge blow-pipe by the direct action of a column of falling water, or the blast in locomotive chimneys, by the abstraction of a quantity of motion due to an instantaneous change in the velocity of the prime mover.

The water having penetrated into the annular space, comprised between the outer surface of the inner tube and the inner surface of the 'lance,' which is determined by their relative positions, mixes with the motive steam, which it partially condenses. From this collision, results a sheaf made up of minute spheres, which, if received into a glass vessel, disappear with the cessation of motion. The spheres are shown by interrupting the 'sheaf,' when issuing from the 'lance,' then, instead of flowing like water in streamlets, it projects particles in every direction which, in certain conditions of light, show that they are, each absolutely, in a state of rotation.

The 'sheaf,' therefore, after the partial condensation of the steam, being composed of spherical particles, is not, on leaving the 'lance,' a jet of liquid water; if it were, its density would be that of water, and its force of projection, calculated from the quantities of water and steam supplied, would be inferior to the quiescent force of the water in the boiler which it has to overcome; but, under the same conditions of orifice and expenditure, experiments prove that its velocity is greatly in excess of that due to water. By admitting a tapering steam-jet to the bottom of a glass funnel of the same taper, it may be seen how the spherical particles are formed in the 'lance,' by its inner surface being brought so near to the outer surface of the inner tube that the mixing of the water with the steam and its partial condensation produce vortices at the origin or springing-line of the 'lance.'

Now, without the tapering of this adjutage, the vortices would produce mere waste of work, but, by turning them into an agglomerate-jet or 'sheaf,' the inventor has obtained onward motion or useful work.

If, therefore, the pressure upon the annular space, formed by the inner tube and the 'lance' be known, it is clear that the steam and water spent may be calculated; the first having less weight and more velocity, the two combined more weight and less velocity, the quantity of motion is undiminished; though the increment of that quantity represented by the acceleration due to the constant pressure be diminished by the momentary vortices; the work of this decrement, if lost for onward motion, is ultimately found in the shape of heat returned to the boiler: the ratio then of water to steam will give the velocity of the 'sheaf,' and its passing the minimum

section of the divergent tube, which is virtually the entrance to the boiler, will be a consequence of certain values of this velocity.

Thus, the only unknown quantity is the pressure between the inner tube and the 'lance,' which is, naturally, function of that of the boiler, the temperature of the feed-water and the annular space by which it meets the steam-jet. This quantity will be, hereafter, determined by the resistance to be overcome.

When leaving the boiler at a temperature due to its pressure the steam escapes from the tuyère, and penetrates a liquid whose temperature is much less, a sudden change takes place—an instantaneous conversion of heat into work. The useful effect resulting from this work is the actual energy or force of projection with which the 'sheaf' in each time-unit is moving: it is the dynamic quantity which will be turned into useful work: *i. e.*, the incorporation of the quantity of motion in with one-half the velocity of the 'sheaf,' or the mass thereof, with one-half the square of its velocity.

With this force of projection, then, the 'sheaf,' after leaving the 'lance' and traversing the space in communication with the atmosphere, encounters the moment it passes the minimum section of the divergent tube the quiescent force of the water in the boiler. The result of the back pressure from the boiler is that the dynamic effect of each successive transversal element being, more or less, according to the quantity of elastic matter held by each, converted into static effect, the sum of these effects represents the total energy of the 'sheaf,' or, in other words, its velocity diminishes, whilst its pressure increases, till it becomes greater than the back-pressure, and injection takes place.

At starting, projected with a velocity greater than that with which a column of water from the boiler tends to flow from the divergent-tube, consequently exerting against this column a superior pressure, the 'sheaf' acts like a water-ram, having, in the space comprised between the orifice of the convergent tube or 'lance,' and the back-pressure valve, energy enough to raise it from its seat. Meanwhile, until the hesitation of the valve to rise, or its vibratory action ceases, and the permanent work is established, a shock is given by the sheaf which, at this moment, has the action of a projectile; it raises the valve intermittently, and this action continues if deprived of its elastic particles without diminishing its velocity; but, if its velocity be reduced to that due to wholly condensed steam, it will not raise the valve.

If, according to the dynamic theory of heat, it be admitted that heat is converted into motive-work, and reciprocally, so that all work, either moving or quiescent, every force, either developed or neutralized by the change of volume or state of bodies, is accompanied by either disappearance or production of equivalent heat,

the quantity of heat spent in the work done by the injector, *i. e.*, the indraught of the feed-water and its injection against the pressure of the boiler, will be, deducting the losses by radiation and contact with the circumambient medium, equivalent to the motive-work.

Now, M. Deloy let into a reservoir containing a given quantity of water, steam from the boiler through the injector with the feed-water cut off. The loss of heat in this operation was not less than that produced by the work of the instrument. The quantity of steam issuing from the tuyère, whence it arrived directly into the reservoir, wherein it was condensed, was less than when it did the work of injecting. This arises from the steam expansion being greater in the first operation than in the second.

DESCRIPTION OF TABLE NO. 1.

To preserve the unity which exists in the original, for which the Author is indebted to M. Turck of the Western Railway of France, 1 foot has been taken for the linear unit, 1 cubic foot for the unit of volume or capacity, 1 cubic foot of water at its maximum density for that of weight, 1 cubic foot of water raised 1 degree Fahrenheit for that of heat, and 1 second for that of time. Thus the ratios which represent weight numerically are expressed in their lowest terms, which, incorporated with the number of pounds in a cubic foot according to the temperature of the water, produce quantities expressed by measures in common use.

The calculations are made for a No. 9 injector, *i. e.*, the diameter of the minimum section of the divergent tube, expressed in millimetres.

a_1 represents the area of this minimum section in parts of a square foot.

The column b gives in atmospheres the total pressure in the boiler.

The column c shows the velocity with which the water in the boiler would, if unopposed, escape by the divergent tube into the atmosphere, deduced from the formula $V = \sqrt{2gh}$; V representing the velocity in feet per second, g the effect of gravity at the end of the first second of fall, and h the height of a column of water which equilibrates the boiler pressure, *i. e.* 33.886 feet for each effective atmosphere.¹

Column d gives the quantity of water which, if unopposed, would be ejected by the divergent tube = a_1 multiplied by the velocity in column c , *i. e.*, $a_1 c$.

Column e shows the quantity of motion which the water would

¹ These figures are taken to accord with the pressures in atmospheres of M. Regnault's heat-tables.

possess at its ejection, *i. e.*, the quantity $a_1 c$ incorporated with the space c passed through in unit of time $= a_1 c^2$.

By multiplying the figures of this column by the number of pounds in a cubic foot of water, the resistance to be overcome, measured in foot-pounds, is obtained.

In the original, this is expressed by grammètres, which are obtained, owing to the unity of French measures, by merely shifting the decimal point.

Now, taking this quantity $a_1 c^2$ to start with, the sheaf, to enter the boiler, must evidently possess, at least, this force of projection, and its increase of temperature must be minimum to enable it to carry the maximum quantity of water compared with the quantity of steam spent, moreover, its velocity must be minimum, the question, then, arises—what must this velocity be? In addition to the resistance $a_1 c^2$ to be overcome, there is, at starting, that due to the difference of the area of the inside and outside of the back-pressure-valve which is about $\frac{3}{10}$ ths, so that there must be $\frac{3}{10}$ ths more pressure on the outside, and if the inside pressure is 10 atmospheres, equal to a column of water $10 \cdot 33 = 330$ feet, there must be on the outside of the valve, a force equal to a column of water 429 feet high to equilibrate the pressure on the inside, and, then, a small additional quantity will raise the valve.

The minimum velocity, therefore, of the sheaf must be that due to a column of water so many times 33 feet as there are effective atmospheres' pressure in the boiler plus $\frac{1}{3}$, instead of $\frac{3}{10}$ ths of their height, *i. e.*, the sheaf must possess a quantity of motion $\frac{1}{3}$ rd greater than that due to the issue of the water from the boiler; this quantity is f in the Table, and represents the power required.

The quantity of water delivered to the boiler depends upon the area a_1 and the velocity with which the sheaf passes through this minimum section of the divergent tube; but here must be ascertained the quantity of water which the sheaf carries, for, if the 'sheaf' be, on leaving the 'lance,' a jet of liquid water, instead of penetrating into the boiler, it will break up and run to waste.

To insure continuous injection, the quantity of liquid water must be, in its limiting ratio, 2 to 1 of uncondensed steam, which reduces to $\frac{2}{3}$ rds of the area a_1 the section a of water in the sheaf when passing through the section a_1 .

Dividing, then, the figures of the column f by the numeric value of a , and extracting the square root of the quotient, the velocity of the sheaf is obtained, which is inserted in column g .

Multiplying the section a by this velocity, there is obtained the quantity of water injected, as given in the column h . Under these quantities' natural numbers are their logs., to which annexing the negative characteristic, and adding thereto log 2.529610, the

number of gallons per hour injected is obtained, and at page 211 compared with the results of observation.

Up to the present time the resistance is determined by the column e , and the power required by the column f : now it becomes essential to ascertain the quantity of steam necessary to give this power, which depends upon its quantity of motion when issuing from the tuyère, *i. e.*, the quantity of water which the steam contains incorporated with its velocity.

This quantity of water held by the steam, or its density, is inserted in the column i (note ¹), and the velocity of the steam in the column k .

¹ The figures in this column are derived from the formula,

$$\frac{V}{V_1} = \frac{P_1^{.955}}{P^{.955}}$$

in which V_1 represents steam raised from the unit-volume of liquid water to the elastic force $P_1 = 1$ atmosphere (of 14·698 lbs. to the square inch, the decimal parts being taken to accord with M. Regnault's Tables), determined by induction to be very near to 1642·5 units of volume.

Multiplying, then, both members of the above equation by this value of V_1 , there results

$$V = \frac{1642 \cdot 5 P_1^{.955}}{P^{.955}}$$

volumes of saturated steam of the various pressures in column b of Table No. 1, the reciprocals of which, or

$$\frac{1}{V} = \frac{P^{.955}}{1641 \cdot 5 P_1^{.955}} = \text{Density,}$$

$$\text{and log. } D = 3 \cdot 2152409 - \cdot 955 \log P,$$

by which the quantities of water in unit volume of steam at the various pressures are obtained.

The approximation of these quantities to those obtained by the observations of Mr. Fairbairn and Mr. Tate, in the following instances, is, putting density observed as unit,

at 1·7918 atmospheres	+ 0·0028
2·8242 ,,	- 0·0088
3·7607 ,,	- 0·0108
4·0859 ,,	+ 0·0129

The densities given in this column are, according to M. Carvalho, in excess; for the weight of the 'sheaf' injected minus that of the feed-water supplied, gives that of the motive-steam. By experiments it is known that this weight of steam, thus ascertained to be in the 'sheaf,' is less than that which the steam issuing from, with the density due to the pressure in the boiler, would give. By reason of the taper of the tuyère, the depression of the steam therein ought to be, and according to M. Turck, is insignificant.

The question then arises, whether, on quitting the tuyère, expansion of the steam takes place? It is true, that if in the steam taken from and returned to the boiler, the quantity of motion is less than that in the 'sheaf' injected, there is work done that must be accounted for.

When (the annular water-space being adjusted to the pressure of steam) quitting the tuyère before the indraught for feed-water takes place, the jet (of several atmospheres' pressure), encountering simply the resistance of the atmosphere, must expand; but, the 'sheaf' once formed, and the work of injection established, then, on issuing from the tuyère, being instantaneously enveloped by the feed-water, the jet must instantaneously collapse. In this way, after this first condensation takes place, an increase of the actual energy in, or work done by, the steam in [each

Dividing the power required, or, the figures of column *f*, by the velocity *k* of the steam, the total quantity of water required to be converted into steam to produce this power, inscribed in column *l*, is obtained, and which, divided by the column *i*, *i. e.*, by the quantity of water contained in a cubic foot of steam, gives the column *m*, or the number of cubic feet of steam per second required to inject the parts of a cubic foot of water found in column *h*.

The column *p* (note ¹) shows the quantity of heat in unit-weight of saturated steam at the temperature indicated in column *θ*.

The column *q* represents the quantity of heat in a cubic foot of steam, and column *r*, the whole quantity spent in the work of injection, which divided by the quantity of water injected from column *h*, produces the increase of temperature in the sheaf, shown in column *s* (note ²), subtracting which from 212°, the limit of the temperature to which the feed-water can be raised in its

each successive portion of the jet, may be accounted for as due to the diminution of atmospheric resistance.

Is it true that, in the steam taken from and returned to the boiler, the quantity of motion is less than that in the 'sheaf' injected? The exact measure of the actual velocity, in the one quantity and the other, as well as the weight of each, must be obtained before answering this question and affirming that there is, on quitting the tuyère, expansion, and consequently diminution of density in the steam.

¹ According to M. Regnault, the excess of heat in unit-weight of saturated steam at 212°, its elastic force being then equivalent to the weight of the atmosphere, over the heat of unit-weight of liquid-water at 212°, is represented by 965·7 units.

Hence, the heat taken in by unit-weight while passing from the state of liquid at 32° to that of saturated steam at 212°, is expressed by $965·7 + 180 +$ (for increased capacity for heat of water at 212°) $0·9 = 1146·6$. This sum, called the 'total heat,' diminishes by the constant quantity 305 for each unit of temperature spent or given out; therefore, unit-weight of saturated steam at 212° in passing to 32°, gives out $305·180$, leaving $1146·6 - (305·180) = 1091·7$ units of heat, insensible to the thermometer. to be given out in passing to the state of liquid water at 32°.

This quantity, then, diminishes as the temperature from 32° increases, but in a slower ratio, and at 212° is reduced to 965·7.

The constant quantity 305 is a calorific capacity of saturated steam differing from, but in intimate relation with, that of gas of constant volume or at constant pressure.

It is the quantity of heat taken in or given out by saturated steam as its temperature is increased or diminished by one degree, when its state of saturation is maintained by compression. $1146·6 + 0·305 (θ - 212°)$ is the expression by which the figures in column *p*, representing the absolute total heat, are obtained.

² To determine the increase of temperature in the 'sheaf,' the escape speed of the motive-steam and the velocity together with the quantity of non-condensed and condensed steam held in the 'sheaf,' must be exactly ascertained: three things which can only be determined within certain limits.

With the same steam-pressure, from a minimum determined by the least quantity, a maximum temperature may be determined by the greatest quantity of steam condensed and non-condensed held by the 'sheaf.'

With a pressure of 9 atmospheres, M. Turck has measured with the centigrade thermometer 122° due to the non-condensed steam enveloped by the 'sheaf.'

Different temperatures are obtained, whilst injecting the same quantity of 'sheaf,' by means of the same quantity of steam, in the same time; for instance:

[1°. Deliver

TABLE No. 1.

[To face page 208.]

RESISTANCE.				POWER REQUIRED								HEAT.					
$a_1 =$ °0006846 $a =$ °0004564	WATER IN BOILER.			IN THE SHEAF.			IN STEAM.					Unit-weight of Steam = 1 cube foot of Liquid Water at its maximum density = 62·425 lbs.					
Total Pressure in Atmo- spheres.	Velocity of Escape to Atmo- sphere.	Quantity Ejected.	Quantity of Motion.	Quantity of Motion.	Velocity.	Quantity Injected.	Water in Unit-volume of Steam.	Velocity.	Water in Steam.	Total.	Section of Tuyère.	Of Steam.	In Unit- weight of Steam.	In Unit- volume of Steam.	Total Spent.	Increase in the Sheaf.	Maximum for Feed- Water.
b	c	d	e	f	g	h	i	k	l	m	n	θ	p	q	r	s	t
	$h = b - 1$	$= a_1 c$	$= cd$ $= a_1 c^2$	$= e + \frac{e}{3}$	$= \sqrt{\frac{f}{a}}$	$= ga$		$= \sqrt{\frac{c^2}{i}}$	$= \frac{f}{k}$	$= \frac{l}{i}$	$= \frac{m}{k}$			$= pi$	$= qm$	$= \frac{r}{h}$	$= 212^\circ - s$
11	147·7	·10101	14·930	19·906	208·8	·095311 979145	·0060157	1904·0	·0104540	1·7378	·00091267	365°	1193·2	7·1779	12·348	130°·9	81°·1
10	140·1	·09590	13·437	17·916	198·2	·090436 956343	54923	1893·6	94838	1·7267	61235	357	1190·8	6·5404	11·293	124·9	87·1
9	132·1	·09042	11·941	15·921	186·8	·085243 930658	49667	1874·3	84945	1·7113	91253	349	1188·4	5·9033	10·105	118·4	93·6
8	123·5	·08459	10·441	13·921	174·6	·07909 901508	44179	1859·0	74871	1·6958	91167	340	1185·6	5·2378	8·877	111·3	100·7
7	114·4	·07831	8·953	11·937	161·7	·073810 868118	39068	1830·1	65229	1·6695	91223	330	1182·6	4·6203	7·713	104·5	107·5
6	104·4	·07149	7·465	9·953	147·7	·067398 828650	33721	1798·2	55348	1·6414	91275	319	1179·2	3·9759	6·526	96·8	115·2
5	93·4	·06394	5·971	7·961	132·1	·060277 780157	28332	1754·6	45371	1·6014	91267	307	1175·6	3·3305	5·334	88·5	123·5
4	80·9	·05538	4·479	5·970	114·4	·052198 717660	22894	1691·5	35315	1·5425	91247	292	1171·0	2·6809	4·135	79·2	132·8
3	66·0	·04521	2·986	3·981	93·4	·042625 629669	17394	1583·5	25140	1·4458	91270	273	1165·4	2·0264	2·929	68·7	143·3
2	46·7	·03197	1·493	1·991	66·1	·030144 479208	11810	1359·0	14651	1·2406	91293	250	1158·3	1·3689	1·697	56·3	155·7
1·5	33·0	·02261	·747	·996	46·7	·021321 328802	08973	1102·4	09035	1·0069	91340	234	1153·3	1·0348	1·042	50·0	162·0

[1864-1865, N.S.]

passage through the injector (note ¹) column *t*, results, indicating the maximum temperature at which the feed-water can be taken from the tank without breaking up the sheaf and causing it to overflow, instead of entering the boiler.

INJECTION FOR TABLE No. 2.

The quantity injected may be diminished, either by diminishing alone the annular space for the water, the steam-orifice being constant, or by diminishing simultaneously these two openings. The difference of ratio to the maximum injected obtained by these two

1°. Deliver the maximum quantity in a given time with a given pressure to a boiler; the 'sheaf' will get in with a velocity and temperature due to that pressure, as shown in columns *g* and *s*.

2°. Diminish the feed-water alone, less water being then acted upon by the steam; the 'sheaf' increases in velocity; but, for each time unit the quantity injected remains the same as previously to the diminution of the water, while the temperature of course increases.

¹ Comparing the figures of this column with those obtained by M. Deloy, by induction from a series of experiments, at which the 'sheaf' breaks up and runs to waste, the following are the results:

8 Atm.	7 Atm.	6 Atm.	5 Atm.	4 Atm.	3 Atm.	2 Atm.
128·5	130·6	132·8	135·5	143·0	149·0	152·6
100·7	107·5	115·2	123·5	132·8	143·3	155·7
-27·8	-23·1	-17·6	-12·0	-10·2	-5·7	+3·1

By which it will be seen that, 1° the calculation fails at 2 atmospheres' pressure; but, from 3 atmospheres there is a margin which widens pretty regularly till 8 atmospheres are reached; and had the observations been extended to higher pressures, this margin would, in all probability, have gone on widening in the same ratio.

2°. By this comparison the same result is arrived at inversely, as that obtained directly from the observations of others, viz., that the temperature of the 'sheaf' increases with the pressure in a slower ratio than that obtained by calculation. On the other hand; the heat taken from, is, saving an insignificant fraction, returned to the boiler; and since "different temperatures are obtained whilst injecting the same quantity of 'sheaf' by means of the same quantity of steam in the same time," considerable indetermination exists in obtaining, by observation, the minimum increase of temperature, i.e., the rise corresponding to the maximum quantity of feed-water injected by a given weight of steam.

As the temperature of steam increases, a greater quantity of heat being given out from the water to produce that increase of temperature, a greater quantity, as compared to steam of lower temperature, is given out insensibly to the thermometer in passing to the state of liquefaction. Let this quantity of heat be 1° at 2 atmospheres' pressure, it would be at 8 atmospheres' pressure of steam 1·12, the relative quantities being $\frac{3524}{2327} = 1·514$ and $\frac{3524}{2327} = 1·514$. This consideration will somewhat help to account for the difference between the results of observation and calculation.

One thing, however, is clear, i.e., at the higher pressures the feed-water may be safely taken at the temperatures indicated in this column.

[1864-65. N.S.]

P

TABLE NO. 2.

Name of Company.	Ratio of Section of Throat (or Minimum Section of Divergent Tube).	Feed-water.		3 Atmospheres' Pressure.			5 Atmospheres' Pressure.			7 Atmospheres' Pressure.			9 Atmospheres' Pressure.		
		Height of draught.	Temperature.	Maximum Injected.	Limiting Ratio to Maximum by diminishing	Water alone.	Water and Steam.	Maximum Injected.	Limiting Ratio to Maximum by diminishing	Water alone.	Water and Steam.	Maximum Injected.	Limiting Ratio to Maximum by diminishing	Water alone.	Water and Steam.
		Feet.		Gallon.				Gallon.				Gallon.			
EST . .	113.3 78.5 = 1.453	1.5		.2802	0.56	0.25		.2802	0.62	0.32		.2452	0.66	0.65	
LYON .	124.6 70.9 = 1.781	"	"	.3105	0.87	"	"	.2717	0.35	0.57		.3292	0.94	0.50	0.50
QUEST .	122.6 61.6 = 1.947	"	63°	.3114	0.23	"	"	.3460	0.41	0.30		.3840	0.50	0.35	0.44
ATLAS WORKS }	151.9 56.7 = 2.749	"	54°	.3878	0.56	"	"	.4849	0.60	0.40		.4849	0.68	0.40	0.43
According to M. Giffard				.2346				.3302				.4034			
According to Table No. 1				.2405				.3401				.4165			

operations may be seen in Table 2, in which is given the quantity of water injected per square millimètre of area of throat (or minimum section of divergent tube) per minute, by instruments of four companies, according to experiments made by the 'Compagnie des chemins de fer de l'Ouest.'

Inversely as the pressure of the steam will be the quantity of water injected by a given weight of steam, whereas, nearly directly as the steam pressure will be the quantity of water injected in a given time.

Thus it will be seen, by reference to Table No. 1, that at 11 atmospheres' absolute pressure, the given weight of steam spent injects nearly ten times its weight of water, whereas, at 2 atmospheres, it carries into the boiler more than twenty times its own weight of water.

The quantity injected per square millimètre of the minimum section of the divergent tube, in gallons per hour, will be, according to the Table:—

Total Pressure in Atmospheres.	11	10	9	8	7	6
Gallons.	32·27	30·62	28·86	26·98	24·99	22·81
Log. added to the log. in column <i>h</i> of Table, is 2·529610.	5	4	3	2	1·5	
	20·41	17·67	14·43	10·21	7·22	

These quantities are calculated with an increase of volume from ·1604 to ·1672 parts of a cubic foot in 1 gallon of water raised from 62° to 212°, at which it is supposed to be injected, and compared with the results of experiments made, by the Author of the Table, in litres per minute—

At 9 atmos.	there is	+	·042	litre per min.
” 7	”	+	·006	”
” 5	”	—	·080	”
” 3	”	—	·177	”

So that at a certain pressure, between 5 and 7 atmospheres, the result would be the same.

OVERFLOW OR RUNNING TO WASTE.

That of steam, of course, tells that the supply of water is not adequate to condense enough steam to reduce the sheaf to as small a section as that of the throat of the injector. But that of water may be caused by, 1°. The section of the jet, though the steam be wholly condensed, being larger than that of the throat;

2°. The jet, though no larger in section than the throat, being no longer a compound jet, but, owing to the total condensation of the steam, a simple jet of liquid, condition not permitting without overflow, injection to take place.

Again, without overflow of either water or steam, the ratio of one to the other in the work of injection might be deemed to be properly adjusted; but this is not so; for, from the limiting-ratio of 2 water to 1 steam non-condensed, the quantity of steam held in, may continue to be increased to the limit of, the sheaf being no larger in section than the throat, thus spending more steam than needed.

The ratio, therefore, of water to steam is not correctly adjusted, save in the case when the water supplied is no more than enough to leave $\frac{1}{3}$ section of sheaf to consist of aqueous vapour, and the steam supply is enough, and no more, to leave $\frac{2}{3}$ section of sheaf liquid water. This is of small practical value, however, because the steam unneedfully used is not wasted, but simply taken from, to be returned to, the boiler.

DEPTH FROM WHICH FEED-WATER MAY BE RAISED varies as the steam pressure. The excess of power in the sheaf is such that, for 3 or 4 atmospheres' pressure, the injector may be fixed 10 feet below the boiler; in that case, however, the feed-water temperature must be less, and the quantity injected by a given quantity of steam will, of course, be less than if the instrument were fixed level with the boiler. The work established, this depth may be carried about 6 feet lower. And, if the traverse of the steam-needle be extended throughout the 'lance,' this depth may be increased to nearly the equivalent of the atmospheric pressure. The excess of power is likewise such that, provided the ratio between the orifice of the tuyère and the minimum section of the divergent tube be not less than that between the pressure of a receiving and of a generating-boiler, the sheaf may be made to enter a boiler wherein the pressure is greater than that wherein the motive steam is generated.

INJECTOR COMPARED WITH PUMPS.

The test of the Injector appears to be its comparison with an apparatus by which the temperature of the water delivered to a locomotive boiler by means as economical, but other than that of impact of the feed-water with the motive steam, may be raised to the same, or to a higher point than that obtained by the injector.

Now Mr. Beattie's apparatus, about to be described, abstracting its first cost and that of maintenance, is one which, by utilizing the heat of the exhaust steam, fulfils the above condition, by delivering the water at the boiling point, for which he claims a saving of fuel to the amount of $13\frac{1}{2}$ per cent. as compared with

any process other than that of the injector, delivering feed-water at the temperature of 50° .¹

This apparatus (Plate 12) consists of two pumps A and B; two double side pipes C_1 and D_1 each containing another pipe C and D; a mixing-chamber E, under the foot-plate, connected, by the pipes F and G, with the pumps; a two-way cock and clack-box H, on the left-hand side of the boiler; and a clack K, on the right-hand side of boiler.

The inner side pipes C and D are filled with exhaust steam, of which a part being condensed by the action of the feed-water circulating through the annular space formed by the outer pipes C_1 and D_1 , passes, on the right-hand side of the boiler, to the mixing-chamber E, and on the left-hand side, either by the drop-pipe and cock L to E, or, by the pipe M, to the tender.

The cock N regulates the water supply from the tender to the mixing-chamber E, enabling the engine-man to keep therein water at a pumping temperature, say 150° , the limit being 180° .

A cock P, on either side of the boiler, shuts off the exhaust steam either when the tank is sufficiently heated, or to increase the blast when required for raising extra steam when ascending long inclines; but it is not often wanted, owing to the use of a fire-box for coal-burning and smoke-consuming, which does not require a strong blast.

The action of the pump A is constant; drawing water from the chamber E, and forcing it through the two-way cock H into the annular space between the left hand side pipes C_0 , C_0 and C C; then across the boiler by the pipe I into the annular space between the right hand side pipes D_1 , D_1 and D D; thence by the clack-box K into the boiler, or forcing at once by the clack-box H, by means of the two-way cock in case of accident, into the boiler. The exhaust steam in the inner side pipes C and D is partly condensed, and flows away through the cocks P to the tender. The pump B is only used in case of accident to the pump A.

By referring to column *p*, Table No. 1, it will be seen that 1190·8 units of heat are absorbed in raising water from 32° to saturated steam at 357° or 10 atmospheres' total pressure.

Now, starting with feed-water at 212° as Mr. Beattie does, to generate steam at 10 atmospheres' pressure, there results

$$\frac{212 - 50}{1190 \cdot 8 - \cdot 305 (50 - 32)} = \frac{162}{1185 \cdot 3}, \text{ and dividing } \frac{1185 \cdot 3}{100}$$

and $\frac{262}{11 \cdot 853}$, 13·7 per cent. is obtained, or a fraction more than Mr. Beattie's claim.

¹ Vide Minutes of Proceedings Inst. C.E., vol. xvi., p. 29.

The question then is, what is there to set off against this saving? The heat spent by the working of the feed-pump, except when this work is done by the quantity of motion in the train during the passage of declivities, is an undeniable set off. There is, however, no data for estimating this quantity other than that one volume of steam will equilibrate one of water; the rest is matter of opinion; the mean of the opinions furnished gives 15 units, and dividing $\frac{15}{6.5}$, or the heat in unit volume of steam at 10 atmospheres—the result is 2.3. In addition to this the Injector can, at 10 atmospheres' pressure of steam, take feed-water at the temperature t in Table No. 1, *i.e.* $87^{\circ}1$; now $87 + 15 - 50 = 52$ to be deducted from the above found 162; dividing $\frac{1185.3}{100}$ and $\frac{162 - 52}{11.853}$, the result is 9.3 per cent.

The opinion of most locomotive Engineers, both at home and abroad, is, that diminution of the blast-pipe orifice is tantamount to increase of back pressure, and therefore they prefer to regulate the indraught for firing by other means; in this case, however, this orifice is diminished. In a condensing-engine, the "back pressure of condensation," due to the temperature in the condenser, is represented by about 104° , but, here the temperature of the condenser is, initially, that of the mixing-chamber, say 160° , and goes on increasing till it reaches 212° .

As soon then as partial liquefaction of the exhaust steam takes place, vapour is given out, and, as the temperature gradually increases, fills the side pipes with vapour of greater density. In other words, the condensing water being, at starting, very near the limiting temperature of indraught by the feed-pump; the indraught of the exhaust steam—which Mr. Beattie affirms is enough to enable him to reduce the blast-pipe orifice—produced by the difference of its temperature with that of the feed-water, after passing through the pump is inconsiderable and goes on rapidly diminishing till this quantity is represented by $230 - 212 = 18^{\circ}$.

In this way it is possible to account for the feeling of many engineers, that the resistance, on the whole, is increased; for, when the quantity of air carried by the exhaust steam into, and the friction in, so great a length as the side-pipes of the column of vapour, which takes part of the place of the exhaust steam, are taken into consideration, the margin between the indraught of the exhaust steam, *i.e.*, the diminution of pressure and that due to the atmosphere is narrow.

¹ *i.e.*, if it be worth while to utilize the exhaust steam; for, if it is with pumps, it will be, though in a less degree, with Injectors by using for this purpose a single side-pipe as is done on the South Eastern railway.—J. E.

Moreover, to this apparatus a donkey-engine must be added at a cost of £40, which is greater than that of the injector itself, to feed the boiler, as the injector does, when the engine is stationary.

There are also the greater extent and liability to incrustation of pipes, their wear and tear with that of a suction-valve dispensed with by the use of the injector, the constant friction, and the succession of shocks, at high speeds, of the pump-ram.

To sum up; leaving out the moot point of increase or diminution of back-pressure; the excess of first cost, and that of maintenance, the greater liability to accidents,—for instance, suppose the passage between the ram and the boiler be obstructed, something must give way, whereas, the same obstruction to the working of the injector would merely break up the sheaf and cause an overflow without damage to either pipes or their joints—constitute so considerable if not an entire set off, that most railway companies, both home and foreign, have adopted the injector for all new engines.

Should, however, Mr. Beattie succeed in utilizing, instead of the heat of the exhaust steam, that now wasted in the smoke-box, the simplicity of the machine would be combined with the efficiency he claims for his present method by heating the feed-water after its passage through the injector. This after-heating is now done with stationary boilers. The disadvantages of pumps are still greater when feeding with cold water. Then there has to be considered, the bursting of feed-pipes from the effect of frost, and the unequal expansion of fire-box plates where the water enters, which are obviated by the use of the injector, as well as by a feed-water heater. Moreover, in getting up long acclivities, it becomes needful to have, beforehand, the tank-water heated; in order, when on the incline, the engine-man being compelled to feed to keep up the steam then spent much quicker, to avoid the reduction of pressure; in this case, in the absence of a feed-water heater, the advantage of the injector is manifested by reducing the pressure in a much less degree.

The case, however, in which the injector can be most advantageously compared with pumps, is that of marine-engines, when the ship may have to lay to, or delay her departure from port from unforeseen causes. In an experiment made by Mr. Robinson, of Manchester, on one of the boilers of the 'Great Eastern,' the donkey-engine, by throwing in a given quantity of water, reduced the pressure 10 lbs., whereas the injector, by throwing in the same quantity, reduced the same pressure only 5 lbs. per square inch.

From the low pressure at which marine boilers are usually worked, and from the power of the injector not being diminished by drawing up the feed-water, a high temperature is given to the sheaf without risk of its interruption. This instrument, therefore,

has all the advantages of a donkey-engine with this one in addition, that the motive steam does more useful work by returning to the boiler the heat taken therefrom.

The mode of working with the injector on the Western Railway system of France is, according to M. Turck, as follows: steam is maintained to the indicated pressure of $9\frac{1}{2}$ atmospheres; going down inclines, during stoppages and in the stations, at which care is taken to arrive with low water, the boiler is filled to the maximum water-level; in those stations where the engine must remain some hours before starting, the steam is at 2, or at most 3 atmospheres, and as soon as the engine is shunted, the injectors are set to work to fill the boiler, using up the steam,—which would with pumps and without a donkey-engine be wasted,—to 0. Some engine-men, when the steam blows off, which seldom happens, heat their tender-water, and, by feeding on the declivities and in the stations, save, as compared with the same boilers fed with pumps, but without a donkey-engine, a kilogramme and a half of fuel per kilomètre.

The application of this instrument as an elevator may be made as follows:—

In drainage of mines, where the small coal is burnt to get rid of it.

When steam is blowing off, as in forges at night. This application has been made at the Atlas Works in Manchester—where the blowing off of the steam was formerly a nuisance to the neighbourhood—to fill up the tanks during the night.

Where warm water is of value, as in the case of railway tanks, and in some factories, such as dye-works.

Where the supply is seldom wanted it saves the first cost, maintenance of, and attendance to, a pumping-engine.

Where absolute certainty, above all considerations of cost, is required, as in the keeping of the tuyères of a blast-furnace cool.

When frosts take place, the elevator, like the injector, gets into working order upon the admission of the steam, even when the whole is one mass of ice.

Where the boiler is far off from its work, as in the drainage of collieries, no one need be detached from his work to start or attend to the elevator, for the height to which water is required to be raised being, in this case, nearly constant, after the steam is turned on, the apparatus becomes self-acting, *i.e.*, needs no adjustment of either steam or water supply, as in the case of feeding boilers.

The communication is accompanied by several diagrams, for which the Author has to thank Mr. John Robinson, and from

which Plate 11 has been compiled ; also by a drawing from which Plate 12 is made, for which he is indebted to Mr. Beattie.

In conclusion, a list is appended of all that has been published, both at home and in France, on the Injector, in which will be found, saving that which M. Turck has had the goodness to supply, the data for everything given in this Paper :—

"Mémoires des Ingénieurs Civils," 1^{er} trimestre, 1860, p. 57.—"Observations," par M. Ermel. 2^e trimestre, 1860, p. 187.—"Analyse du Mémoire de M. Carvalho," par MM. Brüll et Ermel.

"Théorie," par M. Reech. Paris, 1860.

"Notice théorique et pratique," par M. Giffard, 2^e édition. Paris, 1861.

"Annales des Mines," 5^e série, tome xv., p. 169.—Note, par M. Combes.

5^e série, tome xvii., p. 301, Notice et Expériences, par M. Deloy.

P. 321, Discussion d'une Notice, par M. Giffard, par M. Combes.

P. 357.—Résultats des expériences, par M. Villiers.

6^e série, tome i., p. 575.—Recherches théoriques, par M. Résal.

P. 606, Recherches expérimentales, par MM. Minary et Résal.

6^e série, tome iv., p. 517, Injecteur perfectionné, par M. Turck.

"Trans. Brit. Assoc.," vol. xxx., p. 39, On Giff. Ing., by William Froude.

"Proc. Inst. M. E., at Birmingham," vol. ix., p. 39.—On Giff. Ing., by John Robinson.

P. 74, Supplementary Paper, Vol. x., p. 220.—Injector as Elevator, by Charles Wardle.

[Mr. JOHN ROBINSON

Fig. 2.

Fig. 3.

Fig. 1.

Fig. 4.

FEED WATER HEATING APPARATUS.

PLATE 12. VOL. XXIV.

Scale $\frac{1}{2}$ inch = 1 foot.
Ins. 12 9 8 7 6 5 4 3 2 1 0

J.H. BEATTIE, DELT

Minutes of Proceedings, Institution of Civil Engineers, Vol. XXIV, Session 1864-65.

KELL, BRO'S LITHRS CASTLE ST HOLBORN