

Injector and make it work. Steam may be defined as the natural consequence of confining boiling water, and when it is formed it may approximately be considered and treated as being governed by the laws of gaseous fluids; and, according to those laws, there are few things of more importance—as before stated—than the fixed relationship of pressure, density, and temperature. Again, as the weight of steam is an important element in the Injector, it is desirable that we should have a clear idea of what it really means. The true law of the formation of saturated steam—that is steam in direct contact with the water which generates it—it is a very complex affair, and the rules and formulæ are all more or less empirical—that is there is a good deal of assumption about them—but we can get at what we want at present in a plain practical way. The weight of a cubic inch of water is .0361b. (about half an ounce), and if we convert this cubic inch into steam at atmospheric pressure the investment is very prolific, for its volume is increased nearly 1,700 times; or, taking a cubic foot of water, we get 1,700 cubic feet of steam—hence the expression: That the relative volume of steam to water at 212 degrees Fah. is 1,700 to 1. Knowing this, it must follow that the weight of 1,700 cubic feet of steam must be (assuming there is no loss) the same as the cubic foot of water from which it was generated, viz.: $62\frac{1}{2}$ lbs. But the relative volume of steam to water *decreases* very rapidly as the pressure increases, for instance at atmospheric pressure it is 1,700 to 1; but where the steam gauge shows 20lbs., its volume is only 732 to 1, and at pressures of 50lbs., 100lbs., 150lbs., and 200lbs., we only get volumes of 408, 238, 169, and 132 respectively. It will therefore be seen that if we have two boilers, one working at 20lbs., with a relative volume of 732, the other working at 200 lbs., with a relative volume of 132, and if in both cases we use *the same quantity of steam in the same time*, the boiler power required for the 200lbs. example must be $732 \div 132 = 5\frac{1}{2}$ times greater; that is: if four furnaces were sufficient to supply the low pressure boiler it

would take twenty-two furnaces of the same size to supply the high pressure, and this is the reason why in modern machinery and especially in triple and quadruple expansion engines carrying high pressure, it takes such an enormous boiler power to supply very small cylinders. It should always be remembered that the relative volume of steam to water is the only true foundation which in all cases governs the whole of the boilers' proportions, and the importance of this can scarcely be over-estimated; therefore, if we want to find the weight of a cubic foot of steam at any pressure, we have only to divide $62\frac{1}{2}$ by its relative volume and we get its weight per cubic foot.

Returning now to the Injector he would try to show how what had been said applies to its action. If we drop two balls, one iron and the other wood, from the top of the tower of the Sydney Post Office, it is well known that although one ball is say ten times heavier than the other, they will fall through equal distances, attain the same velocity, and strike the ground together at the same moment. The speed attained is quite independent of their weight, shape, or size, for it depends entirely on the *height* from which they fall; and it is evident that had the lighter ball fallen from a greater height its velocity would be augmented in proportion to its increased distance. Now theory and experiment both prove (but only under certain conditions) that the velocity of steam flowing from the steam-space of a boiler is precisely the same as that of a non-elastic fluid of the same *weight* as the steam, and whose height and weight of column would just be equal to and exactly balance the boiler pressure. Also, that in all boilers the velocity of the steam and water must be calculated by the same law which makes light and heavy bodies fall in the same time, the period of fall depending on the *height*, and not on the *weight*. As a practical example, let us take a boiler working at 100lbs. pressure, we desire to calculate the respective velocities of water and steam. To balance the 100lbs. of water pressure in the boiler we simply multiply the pressure in pounds

by the height of column which balances one pound, namely 2·3 feet; therefore the height in this case is $100 \times 2\cdot3 = 230$ feet; and if you can imagine this 230 feet alongside the boiler, and the height of column and boiler pressure kept uniform in both, then the velocity of water from two cocks—one on boiler bottom, and the other in the bottom of the 230 feet pipe—would be the same, and is always equal to the square root of the height $\times 8$, which in this case would be the square root of $230 \times 8 = 121$ the velocity in feet per second, and remember that this is the exact velocity which any body, light or heavy, would attain in falling 230 feet. Now, take the steam from the same boiler and find what its velocity would be. First of all we must find what height the steam column should be whose weight would balance the boiler pressure. If we divide the boiler pressure by the weight of a cubic foot of steam at 100lbs. and multiply the result by 144, the result gives the height of column in feet.

The weight of a cubic foot of steam at 100lb. is $\cdot 2619$ lbs (about $\frac{1}{4}$ lb.), therefore $100 \div \cdot 2619 = 381\cdot 82 \times 144 = 54982$ feet in height. Applying the same rule to find the velocity of the steam as we did for the water, viz.: the square root of the height $\times 8$, we have the square root of $54982 \times 8 = 1875$ feet per second as the velocity of the steam. Dividing 1875 by 121 we get 15·6, showing the velocity of the steam to be $15\frac{1}{2}$ times greater than that of the water. The author hopes the explanation on this important point has been made quite clear, but, in addition, he may add that in all boilers, the pressure on the steam and water being the same, the height of the steam column will be greater than the water column in the proportion of the relative densities of the steam and water, and that in all cases the velocity of the steam will exceed the velocity of the water in the proportion of the square root of the height of the respective columns. Proceeding a step further, he wished them to imagine that when the steam entered the Injector we have the power to instantaneously condense it—say, by passing

it over an infinitely cold surface or space—then we would have a very small contracted jet of water moving with the *same velocity as the steam*, and the result would be that this jet would force its way into the water space of the boilers with a velocity $15\frac{1}{2}$ greater than that of the opposing jet. This, however, is all assumption, and is in fact impossible ; but the instrument is so designed, and the proportions are such as will ensure the perfect condensation of the steam by mixing it with the required quantity of water, which is so regulated that in all cases the velocity of the condensed jet is invariably greater than that issuing from the boiler.

Experience teaches us that steam uncondensed, or even partially condensed, impinging against the water will not drive it back, but a column or jet of *solid* water meeting another of inferior velocity will drive it back, and in all Injectors it is imperative that the water admitted must be of sufficiently low temperature and of such quantity as will ensure perfect condensation of the steam. We must take all the elasticity out of it and convert it into a solid incompressible jet, and its velocity should never be reduced below that of the opposing jet, but should always be considerably higher to ensure reliable working.

The quantity of water required for perfect condensation, the size of the steam and water connections, the capacity and proportions of the various ports and passages, the radius of the curves, the taper of the cones and steam needle or lance, the ingenious method of adjustment, arrangement of check valves, &c., are questions which have been solved by a vast amount of scientific and experimental research ; all these things, however, are quite beyond the scope of the present effort, which is only an attempt to explain the principle and not such details. For the instrument before you (Plate 1) the author is indebted to the courtesy of the Railway Commissioners, and especially to Mr. Henry Howe, who prepared it for him. It is, as you see, a full-sized Giffard's Injector, made by Sharp, Stewart and

Company, and was taken from one of our old locomotives, but you will observe that although the engine and boiler have worn, this appliance is as good as new, and appears to be practically independent of wear and tear. The various parts require very little explanation, because being cut in two in the direction of its length, everything is in section and will be much better understood and appreciated than in a drawing. There are four flanges marked A, B, C, D. A represents the steam from the boiler, which flows freely into the steam cone surrounding the steam needle. B is the water connection having free passage into the combining cone. C is the overflow allowing the water to escape into the atmosphere until the jet is established. D shows check valve and connection to boilers. Generally, the spindles, glands, adjusting screws, &c., explain themselves. The action is simply this, when steam is admitted into the steam cone its velocity is so great that it creates a partial vacuum in the water chamber, and by virtue of the excess of the atmospheric pressure on the surface of the water, forces it to enter the combining cone and mix with the steam, which of course is instantly condensed becomes a solid jet of water, passes the intervening space in the water cone, and past the check valve into the boiler. When the instrument is not working the boiler pressure forces the check valve up against its seat and effectually stops all communication with the boiler.

Having reached this point the author will take advantage of the present opportunity to direct the attention of the older members to a very curious property of steam which is comparatively little known and which is difficult to understand. In a former part of this paper it has been shown that the velocity of steam is theoretically arrived at by finding the height of the steam column in feet, whose *weight* would balance the boiler pressure and that the square root of this column $\times 8$ gave the velocity in feet per second. When spring safety valves came into general use a most exhaustive set of experi-

ments were carried out by Mr. James Brownlee, to ascertain and arrive at reliable data; to determine the velocity of steam through an orifice, and particularly such openings as would be represented by the "lift" of flat-faced safety valves in actual work. Without going into detail he may state that the result of the experiments proved conclusively that the flow or velocity of steam is neither increased or diminished by reducing the outside pressure below 58 per cent. of the absolute pressure of the boilers; or, in other words, the same weight of steam would flow from a boiler carrying 100lbs. into another carrying 58lbs. as would flow from the same boiler into the atmosphere. According to this the velocity (calculated at the density of the boiler pressure) with which steam at any pressure not less than 25·37lbs., absolute, or 10·67 above the atmosphere, would flow through the *best* form of orifice would be 3·5953 times the square root of the height of the steam column, instead of eight times as shown. This, of course, materially reduces the theoretical velocity, and as before stated is difficult to understand. It was only when hunting for information in connection with the Injector that he came across these experiments, and he had no previous knowledge of this very peculiar property. There is no explanation given—only the bare results—but as some of our members may have had some experience in connection with this, the present reference is made in the hope of getting some further information.

Referring to the Injector, there is no doubt that the difference between the theoretical and the actual velocity of the steam is considerable, as it has to pass through various valves and ports which, perhaps, are not of the best form, still the large margin in its favour has always been found to be ample for all practical purposes.

In the early part of the paper reference was made to Mr. Savill's Automatic Injector, which was described at the Institution of Mechanical Engineers, in 1884. The drawing (Plate II, Fig. 1) before you represents Savill's Automatic, Self-starting

Exhaust Steam Injector. The peculiarity of this appliance is the split nozzle, which, it is claimed, renders it perfectly automatic in starting after all and any interruptions. This nozzle is split from the smallest part of the taper of the combining cone, up to a point where there is a much larger passage for the steam and water than at the bottom of the cone. The split part is hinged to the fixed part by a pin joint, and the advantage of this hinged flap is as follows: When the Injector is not working the flap hangs open, and gives a much larger area for the steam to pass, consequently when the steam is turned on, it can flow through the Injector with very little resistance, the great quantity and velocity which can pass through ensures a partial vacuum being instantly formed. When the water reaches the combining cone it is instantly condensed, the strength of the vacuum is increased (exactly as in other injectors), the flap is forced inwards, and forms an ordinary solid nozzle, through which the water passes into the water cone and then into the boiler. If by any means the instrument should stop working the flap opens, allowing a large quantity of steam to pass; a vacuum is created; the water is lifted, instantly condensed, vacuum increased, flap forced inwards, and the instrument is again in operation. The object in designing this split nozzle was to work it by exhaust steam only, and practical experience has given very good results. Speaking approximately, these exhaust injectors can and do feed boilers carrying 75 lbs. per sq. inch, and even higher pressures when the temperature of the feed water is low. On the other sheet (Plat. II, Fig. 2) is shown a complete longitudinal section which, you will observe, shows a considerable difference in the proportions, if compared with the locomotive injector. The steam nozzle in the exhaust injector is of very large bore, and the steam spindle is a fixture. The flap is prevented from opening too far by a suitable projection, which only allows it to open a certain distance, which of course is regulated by the largest bore of the flap, namely at the hinge. In applying the exhaust

injector it is always desirable to fit and fix it below the level of the feed water. For taking the exhaust steam to the injector all that is required is a connection from the exhaust pipe to the instrument, taking care to avoid any elbows, or parts where deposits or dirt may lodge. It is best to connect it to some vertical part of the exhaust-pipe—this ensures it being kept clean. It appears to the author that in these colonies the exhaust injector could and should be utilised to a much greater extent than it is. In a large number of cases the boilers in our large cities, in the mining districts, and on our gold and silver fields, this appliance, if properly fitted, would result in an undoubted saving—in fact, it is all saving, because it is utilising steam that would otherwise be wasted. Practical working has proved that about 15 per cent. of the total feed-water is returned from the exhaust steam, so that where water is scarce this would be a great advantage; besides it would raise feed water at, say, 50 deg. to 190 deg., a difference of 140 deg., and in high pressure engines, whatever back pressure was on the pistons would of necessity be reduced. With regard to the economy of the exhaust over the live steam injector, Mr. Savill states that it is 20 per cent., and sometimes more, in fuel alone, and there is nothing to wear out. He had no hesitation in stating that in every case where a suitable exhaust injector was applied it would save from 12 to 15 per cent. in fuel, and lengthen the life of the boiler.

Referring to other injectors, their name was legion, and they were used for an almost infinite variety of purposes, one of the most modern and important being its utilisation in the application of liquid fuel. It has been vastly improved by the Americans in many of its mechanical details, and there are many different patents; but no matter how they are made, or what work they do, their action is entirely due to the principles he had attempted to explain, and in the whole range of mechanical appliances there was nothing he knew of that furnished a more beautiful illustration of the application of

natural law to mechanical work than the action of the instrument he had attempted to describe. Summing the whole matter up in a condensed form, he hoped what had been said, would make it clear and apparent that the secret of the Injector's working is entirely due to the difference in the velocity of the steam and water when under the same pressure; that the speed of a jet of water from any boiler is always the same as would issue from the bottom of a water column whose *weight* would balance the boiler pressure. Also that the speed of a jet of steam from any boiler is always the same as would issue from a steam column (imaginary) whose *weight* would balance the boiler pressure. As steam is so very much lighter than water, the height of the steam column will always be higher than the water column in the proportion of their different densities, and as the flow of the steam and water is in strict accordance with the laws that govern falling bodies, their respective velocities will always be proportional to the square root of the height from which they fall. Knowing this, we take advantage of the extreme velocity of steam by instantly condensing it with the required quantity of water, which is so regulated, that although the mixing, as a matter of course reduces the initial velocity of the steam, the speed of this condensed, incompressible, solid jet of water is always much greater than the force of the jet issuing from the water space of the boiler. Hence it is, we never experience any difficulty in feeding boilers with their own steam, and against a pressure much higher than that on the steam gauge.

In concluding his paper, he might be permitted to refer to the statement made by our President in his address, viz., that, as an Institution we had attained our majority, and all things considered, we can with fair justification, congratulate ourselves on having done good work. Looking back, all those years seems as yesterday; looking forward twenty-one years, everything appears uncertain, dim and far distant. In the ordinary course of events it is very improbable that any of those who assisted in the Society's formation will be present. Our young engineers,

who have so patiently listened to what has been said to-night, will have taken our places long before that, and very possibly, after all these years have passed, one of them will stand where he did now, describing something more ingenious, more useful and of much greater importance than the Injector. If so, all who may be present then, and who are here now, will not forget this red letter period in our history, and it may be that memory will carry them back to this particular evening, when one of the original members made an effort to explain an appliance generally used, but whose true principle of working was not so generally understood.