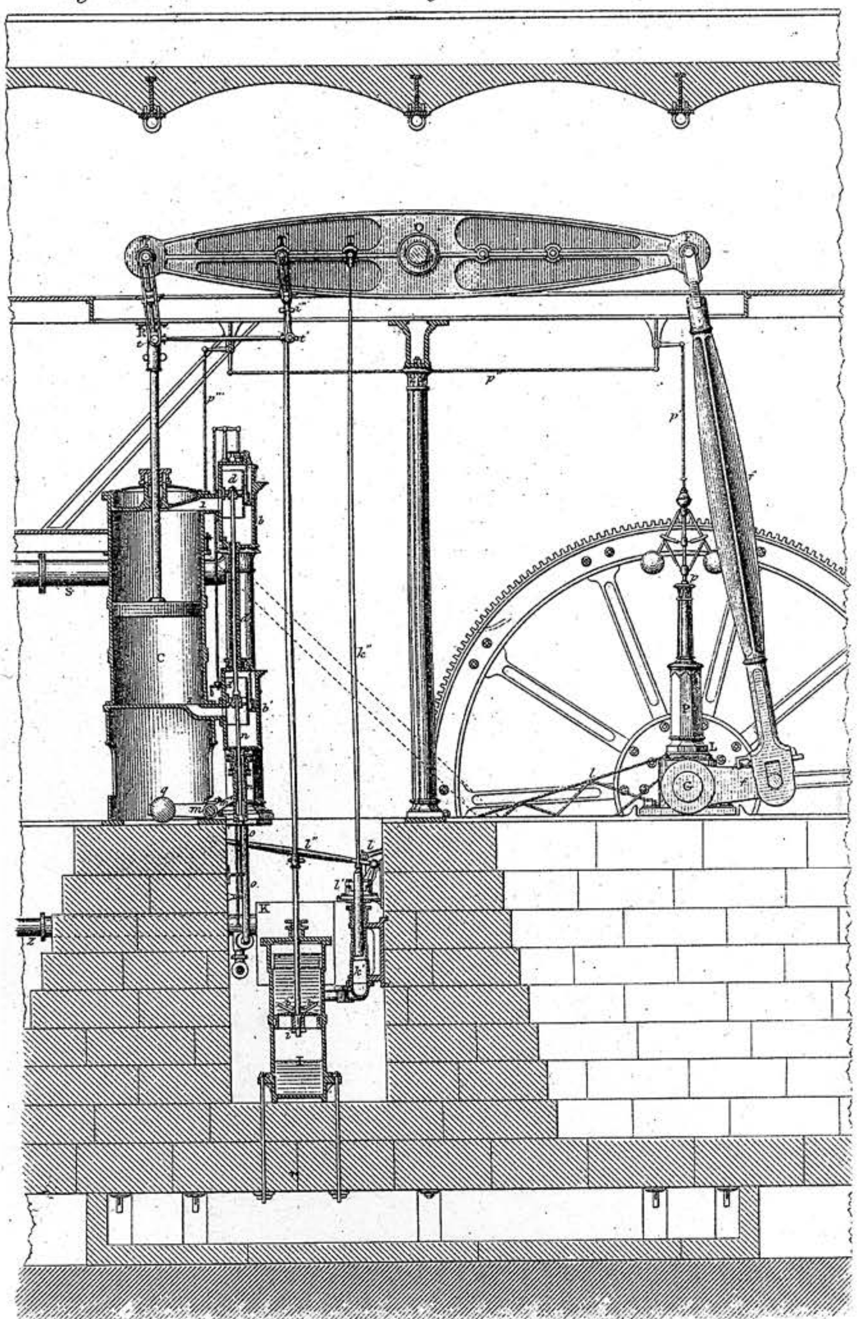
SIXTY HORSES POWER *stationary* CONDENSING ENGINE

as constructed for working Cotton Mills;

by W^m FAIRBAIRN, *Engineer*, MANCHESTER.



Longitudinal Section.

John Weale, 1848. *Reduced & Engraved by G. Gladwin.*

THE

STEAM ENGINE

For the Use of Beginners

BY DR. LARDNER

EDITOR OF "THE CABINET CYCLOPÆDIA"

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RUDIMENTARY TREATISE

ON

THE STEAM ENGINE.

CHAP. I.—HOW STEAM PRODUCES MECHANICAL ACTION.

1. The instrument by which steam accomplishes this is almost invariably a piston, moveable in a cylinder.

A *cylinder* is a tube or pipe, but much larger in its diameter, in proportion to its length, than tubes or pipes usually are. Thus a common proportion for a cylinder is 3 feet in diameter, inside measure, and 4 feet or 4½ feet in length; but this proportion is very variable according to circumstances.

2. The *piston* is a solid plug, fitting the interior of the cylinder with sufficient precision to prevent steam from passing from the one side to the other, but with sufficient freedom of motion to enable it to move along the cylinder without any considerable loss of force to keep it in motion.

3. The ends of the cylinder are understood to be closely stopped by lids. One of these lids is cast with the cylinder, and forms, in fact, part of it; the other is attached to it by screws and nuts, and fitted so exactly that steam cannot escape at the joints.

4. Small apertures are provided at each end of the cylinder, furnished with stoppers or valves, by which steam may be admitted or allowed to escape at pleasure.

5. Now it will be easily understood, that if a blast of steam be admitted at one end of the cylinder it will blow

the piston to the other end: if a blast of steam be admitted at the other end, that which had previously been admitted being allowed to escape, the piston will be blown back again.

If we have the means, then, of taking in a blast of steam alternately at the one end and at the other end of the cylinder, the piston will be blown constantly backwards and forwards from end to end.

The force with which this will be effected will depend on the force of the steam.

6. This alternate motion of the piston from end to end of the cylinder, made with a certain degree of force, could accomplish nothing useful if it were confined within the cylinder; it must be communicated to something outside which is required to be set in motion.

7. This is accomplished by an appendage to one side of the piston, called the *piston-rod*. This is a round rod, firmly fixed into the centre of the piston, and passing through a hole made in the centre of the cover or lid of the cylinder, which I have already described, to be attached by screws and nuts. It must move in this hole as the piston does in the cylinder, so tightly as not to let any steam escape, and yet so freely as not to require any considerable power to urge it.

8. It will be easily understood, that to attain this object very great precision of form is necessary in the internal surface of the cylinder and in the piston-rod. The cylinder is made of cast iron, but the inner surface of it, after being cast, is reduced to a precise cylindrical form by a boring machine. This machine scrapes off all roughness, and reduces every part of the inner surface to an exact circular form, of precisely the same diameter throughout the entire length of the cylinder.

9. The piston, which is flat on either side and circular at its edge, to correspond with the cylinder, is made to fit the cylinder in steam-tight contact, and at the same time to move freely in it by a variety of contrivances which will be noticed hereafter. For the present it will be sufficient to assume that mechanical art, in its present state, enables us to construct pistons and cylinders with so great a degree of precision that no steam whatever shall pass between them, and yet that the motion shall be almost perfectly free.

10. The piston-rod, also of iron, is turned in a lathe so as to be truly round, and uniformly of the same diameter throughout its length. The hole through which it plays in the top of the cylinder is surrounded by a packing of hemp, soaked in oil and tallow, which is pressed against the sides of the piston-rod; and in this way, whilst the motion is free, no steam escapes.

11. The piston-rod thus partakes of the alternate motion which the piston itself receives, and conveys this motion to any object outside with which it may be connected.

12. Thus the primary motion produced by steam power is an alternate motion backwards and forwards in a straight line; but by an infinite variety of well-known mechanical contrivances, this alternate motion may be made to produce any other kind of motion that may be desired: thus we may make it keep a wheel in constant rotation, or move a weight continually in the same straight line and in the same direction.

13. These points will be hereafter explained: for the present we establish the fact that steam can by the means indicated produce an alternate force backwards and forwards along a cylinder with a degree of energy proportionate to the force of the steam, and with a degree of speed proportionate to the rate at which the steam can be supplied.

CHAP. II.—WHAT STEAM IS, AND WHAT ARE ITS PROPERTIES.

1. I have spoken of the piston in the cylinder being driven from one end to the other by a *blast* of steam. This will at once suggest the resemblance of steam to air. Steam possesses, in fact, a set of properties precisely the same as air.

if air were heated to the same temperature as steam, it would, to all intents and purposes, possess the same mechanical properties; and if it were as manageable in other respects as steam is, we should have no occasion to resort to steam engines, but should have nothing but air engines. Air could blow the piston from end to end of the cylinder as well and in exactly the same manner as steam does. It will therefore greatly facilitate the comprehension of the qualities of steam to attend, in the first instance, to the corresponding qualities of air.

2. Air is an elastic fluid,—so is steam.

The meaning of an elastic fluid is one which may be squeezed or compressed into a less bulk; or, on the other hand, which will expand itself into a greater bulk spontaneously if room be given to it.

3. All fluids, however, do not enjoy this property: water does not partake of it at all; it cannot be squeezed by any practical force into less dimensions than it naturally occupies, and whatever room you may give to it, it will not expand into greater volume. If air be enclosed in any vessel, it will spontaneously press on every part of the inner surface of such vessel with a certain force, tending, as it were, to burst the vessel. This is what is called its *elasticity*. If it be squeezed into a vessel of half the size, it will press on the inner surface of this vessel with just double the force; and if, on the other hand, it be allowed a vessel of twice the size, it will spontaneously expand and fill every part of such vessel, but will press on it with a diminished force, amounting to one-half its original pressure.

4. In short, you may by compression reduce its bulk in any required proportion, and its bursting or elastic force will be augmented in exactly the same proportion; and you may, on the other hand, permit it to expand to any augmented volume, and its pressure will be diminished in precisely the proportion in which its volume will be increased.

5. All these are equally qualities of steam.

Air is an invisible fluid,—so is steam. It is a great mistake to imagine that the cloudy vapour that is seen issuing like white smoke from steam vessels or boilers is steam: the moment it becomes thus white and cloudy it ceases to be steam.

These misty particles are particles of water, and not steam. If a glass vessel were filled with pure steam, it would be as invisible as when filled with air.

6. Steam is air made from water.

Air may exist in different states of density,—so may steam. In either case the pressure or elasticity (other circumstances being the same) is in proportion to the density.

7. But as air is everywhere accessible and disposable, it may be asked why we may not use it for those mechanical purposes for which steam has proved so omnipotent, especially seeing that the production of one is attended with great cost and trouble, while the other exists in unbounded quantity, and can be had everywhere and for nothing. To answer this we must consider those qualities in which steam differs from air.

CHAP. II.—HOW WATER IS CONVERTED INTO STEAM, AND HOW STEAM IS RECONVERTED INTO WATER.

1. If any source of heat be applied to water, the first and obvious effect will be to render the water hotter.

2. But to this there will speedily be a limit. It will be found that when the water has attained a certain heat, no further application of heat will augment its temperature, but it will then begin to diminish in quantity, and, as it were, to disappear; and if the application of heat be continued, the water will at length altogether vanish. It has in this case been gradually converted into steam, which has ascended into the surrounding atmosphere and mingled with it.

3. But this escape of the steam may be prevented. Let a second vessel be provided and put in connection with that in which the water is heated, and let the communication with the external air be cut off.

4. The steam produced from the water may be collected in this vessel, and when so collected, and submitted to examination, it will be found, as I have stated, to possess all the mechanical properties of air.

It thus appears that the liquid water is converted into the elastic fluid steam by imparting to it a certain quantity of heat.

5. One of the most remarkable changes which the water undergoes when it passes into the form of steam is its change of bulk, which is quite enormous.

6. It is found that a quart of water evaporated under ordinary circumstances will produce about 1700 quarts of steam, but this proportion varies with circumstances, as we shall now see.

7. Let us suppose that a piston is inserted in a tube, and that under the piston a small quantity of water is placed. For simplicity, let us suppose that quantity of water to be a cubic inch. Let the piston be arranged to press upon the water with a force of 15 lb., the magnitude of the surface of the piston in contact with the water being a square inch; and let us in this case put out of consideration any effect of the pressure of the external atmosphere, this pressure being represented by the 15 lb. imputed to the piston. Let a lamp be supposed to be applied under the tube, so as to heat the water within. The effect of the lamp for some time will be merely that of elevating the temperature of the water, but when the temperature shall have attained to 212° of Fahrenheit's thermometer, then the piston will be observed to begin to ascend in the cylinder, leaving an apparently unoccupied space between it and the water. The quantity of water will at the same time apparently diminish. The lamp continuing to act, the piston will continue slowly to

ascend, and the water slowly to diminish, until at length all the water shall have disappeared.

8. The piston will then be found to have ascended to such a height that the space below it in the cylinder will be 1700 times greater than that which the water originally occupied. This space, which, if seen as it might be through glass, would appear empty, would in fact be filled with the steam produced from the water, which, like air, would be invisible.

9. In this case we have supposed the steam to be produced under a pressure of 15 lb. on the square inch. Let us now, however, suppose things restored to their original state, and the piston to be loaded with 30 lb., or with 15 lb. in addition to the atmospheric pressure, which makes a total of 30 lb. If the same process as before be repeated, it will now be found that before the piston begins to ascend, the temperature of the water will rise, not to 212°, as before, but to 252°; the piston will then begin, as before, to ascend, and will continue to ascend until all the water shall have disappeared. It will not, however, rise now so as to leave 1700 times the original bulk of the water below it, but only the half of that amount, leaving a space for the steam, thus produced, about 850 times greater than the bulk of the water.

In short, the piston may be loaded with any pressure greater or less than that which we have supposed. If loaded with a less pressure, the water will expand into steam of greater volume; and if loaded with a greater pressure, it will expand into steam of less volume. The temperature also at which the water will begin to be converted into steam will vary, being higher for greater pressure and lower for less pressure.

10. When the pressure is doubled, the steam produced will not be of precisely double the density, but will not vary much from that proportion. The reason of the variation—small as it is—is, that when the pressure is doubled, the

temperature of the steam is augmented, and an increase of volume due to such increase of temperature causes the density of the steam which results to be a little less than double the original density. This variation, however, is so small that we may disregard it in practice, and assume as a simple and intelligible rule, that the density of steam is in the direct proportion of its pressure.

11. As it is of great advantage to retain in the memory the extent to which the volume of water is expanded when it is converted into steam, the following accidental proportion will be found useful: a cubic foot contains 1728 cubic inches. Now we shall be sufficiently near the truth, for all practical purposes, if we state that a cubic inch of water evaporated under a pressure of 15 lb. per square inch will produce a cubic foot of steam. This statement is at once so simple and so striking, that it cannot be forgotten.

12. Knowing the volume of steam produced by a given quantity of water under this pressure, the volumes which will be produced under other pressures, greater or less, may be inferred with sufficient practical accuracy by the proportion already given. Under double the pressure, the volume would be one-half; and under half the pressure, the volume would be double. Thus, if water be boiled under a pressure of 30 lb. per square inch, a cubic inch of water will produce half a cubic foot of steam; if it be boiled under 45 lb. per square inch, it will produce one-third of a cubic foot of steam; and in like manner, if it be boiled under $7\frac{1}{2}$ lb. per square inch, it will produce two cubic feet of steam; and under 5 lb. per square inch, three cubic feet of steam, and so on.

13. This proportion would be strictly accurate but for the fact that the temperatures at which the water boils in these cases are different; but the difference due to this need not be now attended to.

14. It may also be observed, that in general, when the water boiled is exposed to the atmosphere, the atmosphere itself produces an average pressure of 15 lb. per square inch, which is understood to be included in the above pressures.

15. Having thus described the manner in which water is converted into steam, let us now see how steam is converted into water.

The steam which is produced from the water in the manner we have described has the same temperature as the water from whence it proceeds. This temperature is indispensable to it. The moment you deprive it of any heat, that moment a portion of it returns to the state of water, and by the continued abstraction of heat from it, it will all return to the liquid state.

16. Let us suppose, in the tube which we have already used for our illustration, that after the piston has ascended, and the water has been all converted into steam, the tube be surrounded by any cold medium, such as a cold atmosphere, the lamp being in the meanwhile withdrawn; immediately a dew will be formed on the inner surface of the tube, and the piston will begin to descend. The dew thus formed is the water reproduced from the steam, which has been restored to its liquid state, in small particles; these are swept down before the piston, and at length, when the piston shall have arrived at its original position, all the water will have re-appeared at the bottom of the tube.

The steam will, in fact, have been reconverted into water.

17. Thus, as heat is the agent by which water is converted into steam, the abstraction of heat is the means by which steam is reconverted into water.

This is one of the most important qualities in which steam differs from air. No known degree of cold is capable of converting air into a liquid, although analogy justifies the inference that some degree of cold, though unattainable by any means yet known, would effect this. There are some airs, in fact, on which art has produced this effect, but it has never been accomplished on the atmosphere.

18. It is precisely this quality, giving us the power of reconverting steam into water at pleasure, which enables us to use steam so extensively for mechanical purposes, and deprives air of the same mechanical utility.

CHAP. IV.—HOW MUCH MECHANICAL EFFECT IS PRODUCED BY THE CONVERSION OF WATER INTO STEAM.

1. The most common and general method of estimating the mechanical effect of any agent is by stating what weight it would raise a certain height, or to what height it would elevate a given weight. Thus, if we are told that such or such a mechanical agent is capable of raising 10 tons a foot high, we have a distinct notion of its efficiency as a moving power. In this view of mechanical effect, it will be seen that we omit the consideration of time altogether whether it be produced in a minute or in an hour, the mechanical effect accomplished is the same. We shall consider it in reference to *time* hereafter.

Now the questions I propose to examine are these;—

2. What amount of mechanical effect is produced when a given quantity of water, as a cubic inch, is converted into steam?

3. To what extent, if at all, is such mechanical effect influenced by the pressure under which the water is evaporated or boiled?

4. Let it be remembered that in all cases the water is supposed to be boiled in a close vessel, furnished with a valve loaded with a given pressure, so that the steam produced from the water shall have a pressure equivalent to that of the valve; in fact, according to our supposition, it must open the valve to escape, and consequently its force must be '*in equilibrio*' with it. But for our present purpose we shall recur to a mode of illustration which will be more easily

apprehended. Let us, as before, imagine a cubic inch of water placed in the bottom of a tube of indefinite length; a piston being placed in such tube, resting on the water, and so fitting the tube as not to permit the steam to escape. Let us suppose this piston, in the first instance, to press on the water with a force of 15 lb., the surface of the piston in contact with the water having the magnitude of one square inch.

5. According to what has been already explained, it will be understood that when heat is applied to the water to convert it into steam, the piston will be forced upwards, to give room to the steam thus formed. Now it has been shown that the room which the steam will thus require will be 1700 times more than its original volume in the liquid state. If then the section of the tube be a square inch, the piston will be raised 1700 inches high, in order to make room for the steam which will be produced. Thus a weight of 15 lb. will be raised 1700 inches, or about 142 feet. The mechanical effect evolved in the evaporation of a cubic inch of water under these circumstances is therefore equivalent to 15 lb. raised 142 feet high. But 15 lb. raised 142 feet high is equivalent to 142 times 15 lb. raised one foot high, or to 2130 lb. raised a foot high. Now this weight is very nearly a ton, and as we are not here concerned with minute fractional accuracy, the following remarkable fact will follow, and may easily be retained in the memory.

6. *A cubic inch of water converted into steam will produce a mechanical force sufficient to raise a ton weight a foot high.*

7. But it may be objected here, that we have supposed the water evaporated under a particular pressure, and therefore at a particular temperature: may it not happen therefore, that if evaporated under a different pressure and at a different temperature, a different mechanical effect will ensue?

To ascertain this, let us suppose the piston to be loaded with 30 lb. instead of 15lb. We have already seen that in such case it would be raised to only half the height, for the steam produced would have double the density. Now 30 lb. raised 71 feet is exactly equal to 15 lb. raised 142 feet, and the same consequences would follow at any other supposable pressure.

8. The above maxim then is general, and it may be assumed that in the evaporation of water the mechanical effect evolved is independent of the pressure under which the evaporation takes place, and is always at the rate of a ton raised one foot for a cubic inch evaporated.

9. It may be well here to observe that this is the *entire mechanical force* evolved, and that it must not be supposed that this effect is practically produced by every cubic inch of water evaporated in the boiler of a steam-engine; a considerable proportion of this force being absorbed by friction and other causes of the waste of power before the *useful effect* can be produced.

CHAP. V.—HOW MUCH MECHANICAL EFFECT IS PRODUCED BY THE CONVERSION OF STEAM INTO WATER.

1. We have seen that a cubic inch of water makes a cubic foot of steam at the common pressure. If then a close vessel be filled with steam at this pressure, and be so exposed to cold that the steam it contains shall be converted into water, it will only occupy a cubic inch for every cubic foot of steam which the vessel previously contained. In fact, the vessel which was previously filled with steam will now have only a small quantity of water in it, the remainder of the space being a vacuum.

2. It is this property by which steam becomes instrumental in doing, by the mere agency of temperature, what is done by the expenditure of so much labour in air pumps and common water pumps.

3. By whatever agency a vacuum can be produced, by the same agency a given mechanical effect will follow; for if a piston be placed in the tube in which the vacuum be created

beneath it, the pressure of the atmosphere will drive the piston down with a force of 15 lb. for every square inch in the section of the piston. In air pumps and common water pumps, where the vacuum is created by pumping out the air, the amount of mechanical force expended in producing the vacuum is equivalent to the amount of mechanical force which the vacuum itself produces when made; but when a vacuum is made by converting steam into water, no mechanical force is expended in producing the effect; and consequently steam thus produces a mechanical agent in its reconversion into water, as well as in its production from water.

4. A cubic foot of steam having a pressure of 15 lb. will therefore, by being converted into water, produce a mechanical force equivalent to that which a cubic inch of water produces when converted into a cubic foot of steam.

CHAP. VI.—HOW MUCH HEAT IS NECESSARY TO CONVERT WATER INTO STEAM.

1. Recurring again to the same mode of illustration, let us suppose the tube and piston as before, a cubic inch of water being below the piston; and let us imagine a lamp burning in a perfectly uniform manner under the tube, so that it shall impart heat to the water at an uniform rate. Let us suppose, at the commencement of the process, the water to be at the temperature of melting ice, but without having any ice in it. Let the time be then observed which shall elapse from the first moment of the application of the lamp to the moment at which the water begins to be converted into steam, and let us suppose this interval to be an hour. The application of the lamp being continued, as before, let the process of evaporation go on until all the water shall have been converted into steam. It will then be found that the time necessary to complete the evaporation will be $5\frac{1}{2}$ hours.

2. From this then it follows, since we suppose the action of the lamp to have been uniform, that to convert a given quantity of water into steam requires $5\frac{1}{2}$ times as much heat as would be necessary to raise the same water from the freezing to the boiling point.

3. This is a fact of such capital practical importance that it ought to be engraven on the memory.

It follows from it, that if a given weight of fuel is consumed in raising a quantity of water from the freezing to the boiling point, $5\frac{1}{2}$ times such weight of fuel will be consumed in converting the same water into steam.

4. There is another point of view in which it is both interesting and important to regard this fact.

If a thermometer be immersed in the steam which shall have been produced from the water, it will show that the steam has the same temperature as the water: thus, if the water were boiled under the usual pressure of 15 lb. per square inch, its temperature would be 212°; the same would be the temperature of the steam into which it would be converted.

5. But it will be naturally asked in this case, what has become of the enormous quantity of heat which has been supplied by the lamp? If in an hour, while the lamp was raising the water from 32° to 212°, it imparted to such water a quantity of heat sufficient to raise it 180° higher in its temperature, it must have imparted an equal quantity of heat in each succeeding hour, and in $5\frac{1}{2}$ hours it would of course have imparted as much heat as would have added $5\frac{1}{2}$ times 180°, or 990°, to 212°, the temperature of the water, supposing the latter not to have been converted into steam: the water would thus, had it not been converted into steam, have been raised to the temperature of 1202°, or about 400° hotter than red-hot iron. But in the present case, in which the water passes from the liquid to the aeriform state, no augmentation of temperature has taken place at all; the steam which has received, and which

actually contains, all this enormous amount of heat, being no hotter than the water which contained nothing of it. Where is the heat then? And why is it not felt or indicated by the thermometer?

6. The answer to the first question is easy. It can be practically proved, as we shall presently show, that the heat is in the steam. But the second question reaches one of the final points of science, and cannot be answered. The heat which is in the steam, and yet neither sensible to the touch nor indicated by a thermometer, is said to be *latent*.

7. But we must not be deceived by the use of this word; it is merely a name given to the fact that the heat is not sensible, but it discloses to us no reason for that fact.

8. It is assumed that the heat has been employed in converting the water from the liquid to the aeriform state, and being employed in maintaining the water in such a state, is not sensible to the thermometer. This, however, is after all but another mode of stating the fact, and is no explanation of it.

9. I observed, that the 990° of heat is in the steam, though not sensible to the thermometer. We might perhaps be justified in considering this as proved, inasmuch as the lamp must be supposed to impart heat uniformly during its action, but we can give a very decisive practical demonstration of it.

10. Let a cubic foot of steam of the temperature of 212°, which has been produced from a cubic inch of water, be supposed to be contained in a close vessel. Let $5\frac{1}{2}$ cubic inches of water, at the temperature of 32°, be injected into this vessel. This cold water, mixing with the steam, will reduce the steam to water, or, to use a technical term, will *condense* it, and we shall find in the vessel $6\frac{1}{2}$ cubic inches of water; namely, the $5\frac{1}{2}$ cubic inches which were injected, and the cubic inch which was contained in the vessel in the form of steam, occupying a cubic foot, but which has now become water, and occupies only a cubic inch. These $6\frac{1}{2}$

cubic inches of water will have the temperature of 212°; that is to say, the same temperature as that of the steam which was condensed.

Now it is evident that in returning to the state of water, the steam has given out as much heat as has been sufficient to raise the 5½ cubic inches of water which were injected into the vessel from 32° to 212°; and yet the cubic inch of water into which such steam has been converted has itself the temperature of 212°, being the same as that which it had when in the form of steam. It is clear, then, that the 990° of heat which were in the steam are now in the 5½ cubic inches of water which were injected, and have raised this, as must have necessarily have been the case, from 32° to 212°.

11. It is therefore demonstrated that steam has in it as much heat insensible to the thermometer and to the touch as would be sufficient to raise 5½ times its own weight of water from the freezing to the boiling point.

12. This result has an important relation to the economy of steam power. The heat supplied by any fuel of uniform quality, and used in an uniform manner, will be proportionate to the quantity of such fuel consumed. It follows, therefore, that it requires 6½ times as much fuel to convert water into steam, supposing the process to commence with the water at 32°, as would be sufficient to boil the same quantity of water. If the process be supposed to commence at the more ordinary temperature of 60°, then a still greater proportion of fuel will be necessary for evaporation.

13. I have supposed throughout this exposition that the water has been evaporated under the common pressure of 15 lb. per square inch, and at the temperature of 212°; but it may be asked, what would be the result if the process were conducted under a different pressure and at a different temperature? Might it not happen that the evaporation would be effected with a greater economy of heat, which would be an important fact in the application of steam power?

14. Such, however, is not the case. It is found that no matter what the pressure may be under which the process is conducted, the same lamp, or other uniform source of heat, acting on the same water, will take exactly the same time to convert it into steam. It is true that the quantity of what is called *latent heat* will be different, and will be diminished as the pressure is increased. Thus each degree which is added to the temperature at which the water boils by increase of pressure, will be subtracted from the latent heat of the steam. The manner in which this remarkable fact is usually expressed is, that the sum of the latent and sensible heats of steam is always the same, namely about 1200°.

15. Thus if water be evaporated under such a pressure that its boiling point shall be 400°, then the latent heat of the steam produced from it will be 800°; if it be evaporated at 300°, the latent heat will be 900°, and so on.

16. This is curious; but the important fact is, that the consumption of fuel in the conversion of water into steam is the same, whatever be the pressure of steam produced.

CHAP. VII.—HOW STEAM PRODUCES MECHANICAL FORCE BY ITS EXPANSION.

1. We have seen how a piston is urged from one end to another of a cylinder with a definite force by allowing steam to flow in upon it, and that increased efficacy is given to this by creating a vacuum on the side towards which the piston moves. The steam in this case is supposed to flow from the boiler, and to press the piston forward with a certain uniform force. The piston advances because a fresh portion of steam which enters the cylinder requires more room, to give it which the motion of the piston is necessary.

When as much steam has entered in this manner as is sufficient to fill the cylinder, then the piston will be driven to the extreme end of it. Now it is well to observe that in the production of this effect no quality proper to steam, or which distinguishes steam from any other fluid, is concerned.

If a liquid (water for example) were made to flow into the cylinder with the same pressure and in the same quantity, it would produce precisely the same effect; in fact, the steam acts thus not because it is an *elastic* fluid, but because it is a *fluid*, and is urged from the boiler with a certain force.

2. I now come to notice, however, a mode of action in which steam performs what an inelastic fluid could not perform; one, in short, in which it produces a mechanical effect in virtue of that property which steam enjoys in common with air and other gaseous fluids, and in which inelastic fluids, such as water, do not participate.

3. Let us suppose that the steam flowing into the cylinder acts upon the piston with a certain definite force, as one ton, and continues so to act as long as it enters the cylinder.

4. Now let us imagine that when the piston has been thus pushed to the middle of the cylinder, the aperture at which the steam enters is suddenly closed, so as to prevent any fresh supply. The piston will then be no longer pushed forward by any increased quantity of steam coming from the boiler. It will, nevertheless, be pressed by the elastic force of the steam, just as it would be by the elastic force of air under the same circumstances; it will still be pressed on by a force of one ton, supposing that no adequate resistance obstructs its motion. It will not, therefore, come to rest, but will continue to advance. As it advances, the steam, expanding into a larger space, will acquire a proportionally diminishing elastic force, and will press on the piston with a force less than a ton, in exactly the same proportion as the space occupied by the steam is greater than half the cylinder. Ultimately, when the piston arrives at the end of the cylinder, the steam, which originally filled half the cylinder, will fill the whole cylinder; and the pressure upon the piston, which was originally a ton, will then be half a ton.

5. It appears evident, then, that while the piston is thus moved through the latter half of the cylinder, it is urged by a continually decreasing force, which begins with a ton, and which ends with half a ton.

6. If we could calculate the average amount of this moving force, we could at once declare the mechanical effect which is produced through the latter half of the cylinder in virtue of the expansive power of the steam.

7. At first view it might appear that the average pressure must be a mean between the original pressure of a ton and the final pressure of half a ton, and that such mean would therefore be three-quarters of a ton. But such a conclusion would be erroneous.

8. The method of calculating the exact average of a force decreasing in the manner we have described, requires principles of the higher mathematics which could not be introduced properly here. By the application of these principles it appears that the exact average of the varying pressures, in the case we have described, would be 1545 lb.

9. The mechanical effect, therefore, obtained in this way from the expansive action of the steam would be equal to 1545 lb. driven through a space equal to half the length of the cylinder. It appears, then, that nearly 75 per cent. has been added to the original mechanical efficacy of the steam by this expedient.

10. It may be asked whether there be any limit to the application of this principle. It is known that other fluids, having the same natural properties as steam, are capable of expansion indefinitely, and it might at first be imagined that there is no limit to the augmentation of the mechanical force which might thus be obtained from steam; but practical considerations show that there are not only limits, but comparatively narrow ones, to its application.

11. It will be observed that the piston, which is urged by the force of expansive steam, is acted upon by a continually diminishing power of impulsion. When the pressure of the

steam becomes by expansion less than the load which such piston drives through the intervention of machinery, including the natural resistance of the machinery itself, then it is clear that the moving power will cease to be efficacious, and that the piston must come to rest.

12. The inertia of the machinery may continue the motion somewhat longer than the moment at which an equilibrium takes place between the resistance of the load and the pressure on the piston, but this effect must soon expire.

13. The expedient by which the expansive principle may be most conveniently extended is to use, in the commencement, steam of high pressure and great density; such steam may allow of considerable expansion before it loses so much of its force as to be reduced to an equilibrium with the resistance to the piston.

14. In all cases the expansive principle evidently involves a continual variation in the impelling power of the piston.

Now it seldom happens that there is any similar variation in the resistance which the piston is required to overcome; and in that case an irregularity of action would ensue. In the commencement, the energy of the impelling force being greater than the resistance, an accelerated motion would be produced, and towards the end, the impelling force becoming less than the resistance, a retarded motion would be the effect. A great variety of contrivances have been suggested by mechanical inventors to equalise this varying action,—

15. The most common and the most beautiful of which is the *fly-wheel*. This is a heavy wheel of metal, well centered, and turning upon its axle with but little friction, so that the force necessary to keep it in uniform motion is inconsiderable. The varying action of the piston is transmitted to this wheel. When the impulsive force is greater than the resistance of the load, the surplus is imparted to the wheel,

to which it gives a slight increase of speed. Owing to the great mass of matter in the wheel, an increase of speed which is scarcely sensible absorbs an immense amount of moving force. When the impulsion of the piston by the expansion of the steam becomes less than the resistance, then the momentum of the wheel acts upon the load, and that portion of surplus force which was previously imparted to it is given back, and the wheel assists, as it were, the piston in moving the load when the latter becomes enfeebled by the extreme expansion of the steam.

16. The fly-wheel is thus, as it were, a magazine of force which gives and takes according to the exigencies of the machinery. When the moving force is in excess, the fly-wheel absorbs the surplus; when the moving force is deficient, the fly-wheel gives back what it absorbed.

17. Cases occur, however, in the arts in which the resistance to be overcome by the piston is of a gradually decreasing nature. In such cases, the expansive action of the steam, being also gradually decreasing, may be kept in equilibrio with the work without the intervention of the equalising action of the fly. Thus if the piston work a pump by which a column of water is raised, which column flows off at the top, the length of the column, and therefore its weight, is greatest when the buckets of the pump begin to ascend, and least when they arrive at the summit of their play. The weight in the buckets is in this case of continually decreasing amount, like the decreasing force of expanding steam.

18. But in most cases some equalising contrivance is necessary where the expansive principle is extensively used, and where any thing approaching to uniform action is necessary.

19. The expansive action of steam is applied in steam engines in various ways, but by far the most usual is that which we have described in the above illustration, by cutting off the supply of steam at some point before the completion

of the stroke. In some cases it is cut off at half-stroke, in some at one-third, and in some at much smaller fractions of the entire stroke.