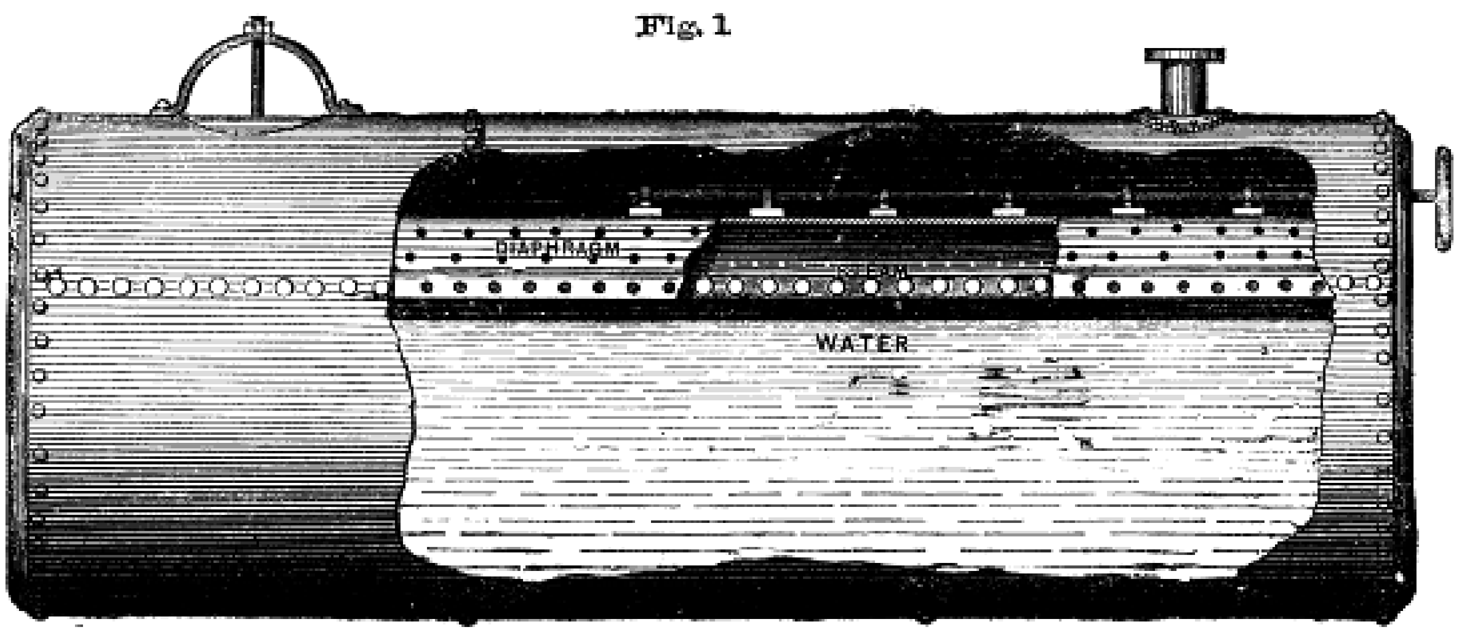
intelligent mechanic knows just what laws govern running belts. He knows, to start with, that perfectly level and parallel lines of shafting and pulleys, turned up with exactly similar faces, will, if the pulleys are in perfect line, run perfectly true. Now, with this knowledge, which he knows is just as positive as the law governing falling bodies, or any other well proven natural law, is he not mulish not to conform to a condition which he knows is absolutely infallible?

Fig. 1



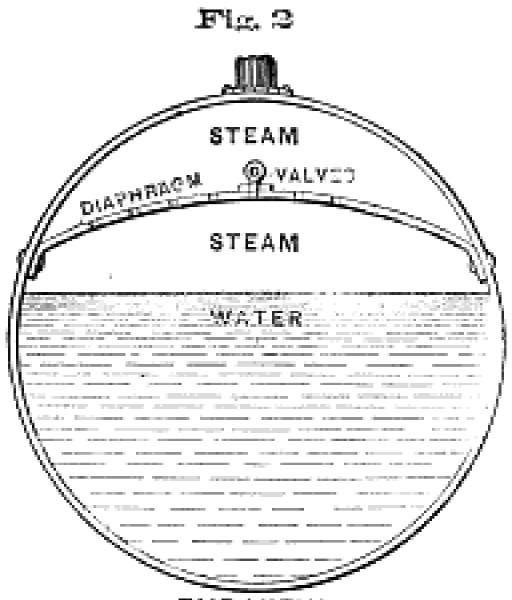
SIDE VIEW

Boiler Explosions---The Cause and the Remedy.

BY THOMAS KAYS.

Since the introduction of steam as a motive power, and in the face of continuous investigation, the cause of steam boiler explosions has until recently remained a profound mystery. The theories of explosions were numerous. The most prevalent were "low water," "hot iron," "high pressure," "mere escape of steam," "superheated steam," "electrical," "gaseous," and the "spheroidal." The

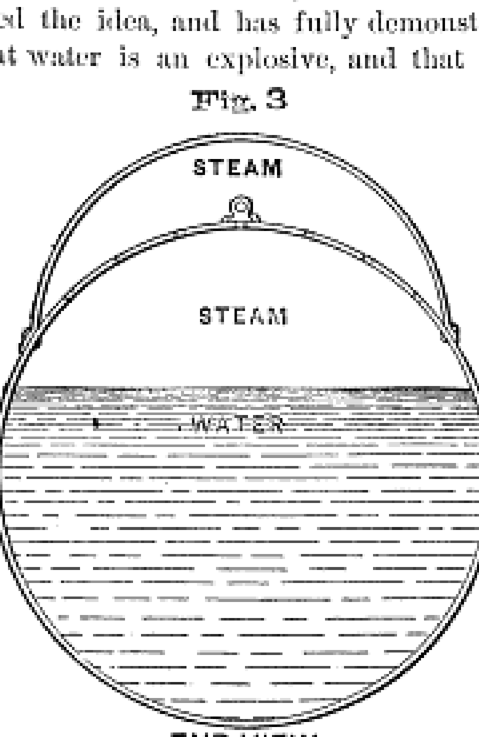
Fig. 2



END VIEW

theory most generally accepted was that of low water. This theory was in conflict with facts as established by unquestionable evidence, and therefore many refused to accept it. The other theories were alike erroneous, and the result was much confusion of opinion upon the subject. The real cause was discovered by Daniel T. Lawson, of Wellsville, O. He conceived the idea, and has fully demonstrated the fact, that water is an explosive, and that all steam

Fig. 3



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boiler explosions are caused by the explosion of superheated water; that the explosion occurs upon a sudden reduction of pressure followed by a sudden check to the exploding water, the result of which is a striking blow far in excess of the tensile strength of boilers.

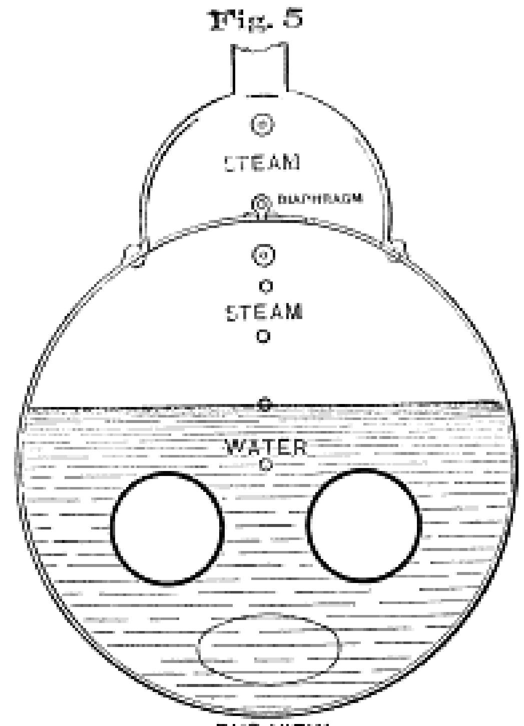
The Lawson theory, briefly stated, is this: The only explosive material about a steam boiler is water; and water, when superheated, which can be done only under pressure, will explode upon a sudden removal of that pressure, with a force quite comparable to that of dynamite.

The boiling point of water varies with pressure. In a vacuum water boils at 70° sensible heat. Under atmospheric pressure it boils at 212°, and cannot be made hotter unless confined under additional pressure; because the escaping steam carries off the heat as fast as fire can impart it. In a steam boiler under 10 pounds pressure it boils at 241°; 50 pounds, at 300°; 100 pounds, at 340°; 200 pounds, at 389°.

Water, when heated to the boiling point, requires 966° additional heat to change it from the state of water to the state of steam. This change is substantially instantaneous at all pressures. As each molecule of water absorbs the last of the 966° it instantly explodes into steam. As the last degree is absorbed, cohesion is overcome and repulsion becomes the predominant power.

The change of steam to water is also instantaneous.

Fig. 5



END VIEW

Steam remains in its new state only so long as it retains the 966° of latent heat, and the moment it at full volume, with only 212° of sensible heat, parts with one of these degrees of latent heat it returns to water.

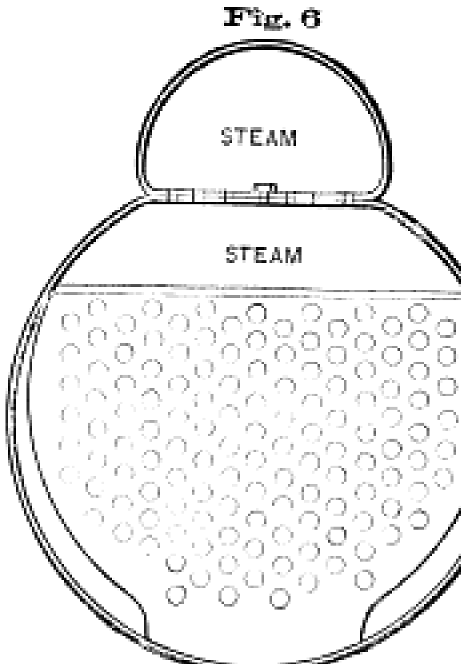
The explosion of water is similar to that of gunpowder in some respects, but different in others. Each grain of gunpowder passing from the solid to the gaseous state explodes when it has absorbed a certain degree of heat. So with water. Each molecule of water, at the instant it has absorbed 966° of heat above the boiling point, explodes and passes from water into steam. The expansive quality of the two is different, powder increasing in bulk 800 times, while water increases 1,720 times. The mode of exploding, and the general result—large and sudden increase of volume—are similar. In other respects they differ widely; the explosion of powder is by chemical action; the explosion of water is a physical change only.

Water differs widely from gunpowder, and all other explosives, in another remarkable particular. Only a portion of the water may explode—one molecule, the half, or the whole mass. These various amounts, in exploding, produce results ranging from violent explosions to mild ruptures and the safe operation of the boiler.

When a grain of powder starts to go from the solid to the gaseous state no power can stop it. It may be confined, but combustion, once begun, goes on to completion. So with a molecule of water. It may be put under such pressure that it will not fully expand, but, once b e g u n, it changes its state from water to steam.

The true source of the development of the great destructive power in a steam boiler is the sudden *concentration* of the sensible heat in the water above 212° (or above 70° in the case of a vacuum caused by

Fig. 6

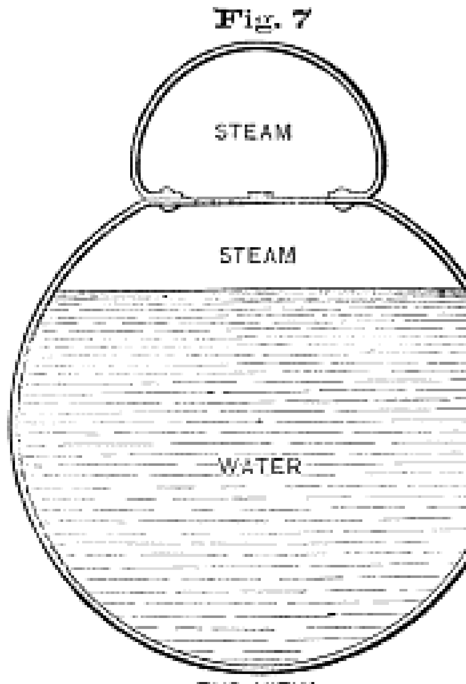


END VIEW

the condensation of steam) into a part of the molecules of water, passing into them the 966° necessary to change them from the state of water to the state of steam.

That the stored heat in a boiler concentrates to form steam is shown by familiar experiments: As, for instance, causing water at less than 212° to boil

Fig. 7



END VIEW

by placing it in a vacuum, or by merely condensing the steam over heated water in a bottle. Again, take a steam boiler under a pressure of 100 pounds and a corresponding temperature of 340°. Remove the fire, and the formation of steam will cease. After a short time raise the safety valve, and the water will begin to boil, and generate and give off steam continuously as the pressure is reduced, until a temperature of 212° is reached, and enough steam will be thus generated and blown off to fill the boiler very many times.

These tests show that the boiling point of water is lowered by simply diminishing the pressure. They show this, and also show the true theory of boiler explosions. They prove in the most conclusive manner that the sensible heat above 70° stored in the water concentrates in a part of the molecules of water, giving to them the 966° necessary to change them into steam. The water ceases to boil, no heat is applied, and by merely reducing the pressure the water again boils. The 966° above the boiling point necessary to cause ebullition are not absorbed from the fire at the instant the water begins to boil the second time. They are already stored up in the water.

Take a boiler containing 10,000 pounds of water at a pressure of 200 pounds, and corresponding temperature of 389°. Suddenly reduce the pressure to 50 pounds per square inch, under which pressure water explodes at 300°. There are stored in each of the 10,000 pounds of water 89° of sensible heat above the exploding point—in the aggregate 890,000 thermal units, enough to convert 921 pounds of this superheated water into steam. In an instant these 89° of sensible heat in each pound of water are absorbed by the molecules of water at the surface, and for a considerable depth, and suddenly these 921 pounds of superheated water explode into steam.

Thus it will be seen that there is sufficient destructive power stored in the boiler when thus put in action to cause an explosion. If the reduction of pressure caused by the withdrawal of steam be moderate, and such draught be continuous and uniform, there will be no danger; but if the draught is considerable in quantity and instantly checked, the nascent steam thus suddenly formed and thus suddenly checked will give an impact or striking blow upon the shell of the boiler, the aggregate force of which is equal to the weight of the water before it passed into nascent steam multiplied by the square of the velocity with which it strikes.

The instantaneous check to the exploding water acts upon the boiler with the same effect as that produced by quickly closing the valve of a water main. In the one case it is the weight of the falling water, and in the other it is the force of exploding water, but the striking effect of the blows is the same, and is measured by the same rule.

The distinction between rupturing and exploding is generally overlooked. When a boiler gives way at a weak point, resulting in damage, it is often called an explosion. When ruptured by mere pressure, the force exerted upon the shell being gradual and uniform, the weak point yields while the balance remains intact. Serious damage may result, but a uniform and unobstructed flow of steam never produces the phenomenon properly called an "explosion."

With an explosion the actual destructive force exerted is not measured by the tensile strength of the boiler, nor by the regular pressure of the steam. The force is far in excess of either—five, ten, and often twenty times as great—an immense aggregate concussive and destructive force, that tears asunder the weak and the strong parts at the same instant and demolishes everything within a large radius.

All writers on steam boiler explosions, in trying to account for their violence, have made the mistake of commencing the calculation at a point of time after the rupture has commenced. The fact is, there is violent internal action at the instant preceding the actual rupture of the boiler, and the rupture is the result of such action. Rupture may be caused by the mere pressure of steam, but it is usually caused by an internal concussive force. It is certainly illogical to say that boilers are ruptured or burst by mere pressure while working with a pressure of only one-fifth their actual tensile strength.

The rational solution of a steam boiler explosion is this: The water in the boiler, under pressure, is superheated, and possesses a highly expansive power. Upon a sudden removal of the pressure, without a corresponding reduction of the temperature, it starts into violent evaporation. This mass of nascent steam is checked by coming in contact with the solid and unyielding shell of the boiler. The result is that the aggregate force of this nascent steam strikes every square inch of the shell of the boiler at the same instant and with the same force, and with a power far in excess of the tensile strength of the boiler; and, moreover, this force is augmented at the instant the shell gives way by an immense reserve power caused by the further evaporation of the water in the boiler. This theory is in unison with natural laws, and upon it every explosion, bursting or rupture of steam boilers can be fully explained, and cannot be upon any other.

Remedy.—Mr. Lawson having discovered the cause, naturally turned toward the remedy, which is a simple one, and consists in the construction of a boiler with a partition plate or diaphragm dividing it into two compartments, the lower one containing water and the upper containing steam only. The steam passes from the lower to the upper compartment through numerous small perforations and a number of small valves in the diaphragm. The aggregate openings of the valves and perforations should be less than the valve through which the engine is supplied. By this means the pressure upon the surface of the superheated water is kept approximately uniform, and all sudden explosions of any dangerous quantity of water into steam, and consequent striking blows, are avoided.

Boilers thus constructed and arranged are protected against explosions, whether the water wholly or partially fills the water compartment. If wholly filled, a sudden reduction of pressure in the steam compartment can instantly affect only the surface of the water to the extent of the aggregate area of the perforations and valve orifices, and no dangerous quantity of water can be thus exploded. As the pressure upon the water below the diaphragm is thus slightly reduced, small portions of the water pass into steam and maintain uniformity of pressure.

If the water should get low, thus accumulating an unusual quantity of steam below the diaphragm, there can be no danger of an explosion. The discharge of steam from the ordinary boiler into the empty pipes and cylinder upon the sudden opening of the valves, is at a velocity of over 100,000 feet per minute, and for an instant there is a great reduction of pressure upon the surface of the superheated water. This cannot occur with the Lawson diaphragm in a boiler. With it the passage of steam from the water compartment below the diaphragm to the steam space above it is limited to that quantity used by the engine with the piston moving at the rate of say 600 feet per minute, and cannot exceed this precise amount to any great extent, although the steam may, from some unusual cause, be temporarily rushing from the steam space above the diaphragm fifty times as fast. The diaphragm limits the quantity of steam discharged from the water compartment to the exact amount necessary to drive the engine in full operation, and the liberation of this amount at such uniform rate can be attended with no possible danger.

The Lawson diaphragm is to the steam boiler what the air chamber is to the hydraulic ram. It performs a similar but much more important function. The elasticity of the air moderates the otherwise solid blows of water upon the pipes; the diaphragm preserves uniformity of pressure upon the water, and thus prevents its explosion and the consequent violent and irrisistible concussive blows upon the shell of the boiler.

Explosions are thus prevented, not by extra strong boilers, but by preventing the occurrence of the cause. Boilers thus constructed can be safely operated at a pressure closely approaching their actual tensile strength. The invention is applicable to every style of boiler, and can be readily applied, internally or externally, to new or old boilers.

Figs. 1 to 7 fully illustrate the invention. Figs. 1 and 2 show an internal and Figs. 3 to 7 an external application. Fig. 3, moderate pressure; Figs. 1, 2 and 5, high pressure; and Figs. 6 and 7, very high pressure.

The ideas of Mr. Lawson, as here exemplified, are being put in practice by the Lawson Non-Explosive Boiler Co., of 157 and 159 Broadway, New York, which is engaged in manufacturing steam generators of this type.

Up to June, 1881, no person had ever intentionally exploded a boiler in accordance with any certain theory or plan, or with a knowledge of the true cause. On the 16th of that month, Mr. Lawson, at Munhall, near Pittsburgh, Pa., publicly tested his theory, and exploded a boiler of the ordinary style having a tensile strength of 768 pounds, at a pressure of but 290 pounds, being 478 pounds less than the actual strength of the iron. The experiment was made by suddenly discharging a considerable quantity of steam at 290 pounds from the boiler into a closed cylinder, the explosion occurring at the instant the cylinder was filled.

In March, 1882, he made further experiments at the same place, under the inspection of a commission of United States engineers, appointed by the Secretary of the Treasury, and fully tested a boiler with his invention attached. The boiler having the Lawson diaphragm, and being 30 inches in diameter, with only 18 inches of water, running down to 11 inches, 4 inches below the fire-line, stood every test of rapid escape and sudden check of steam up to a pressure of 300 pounds, without the slightest injury. The same boiler, with the center of the diaphragm removed, reducing it to the ordinary style boiler, with 22 inches of water, 7 inches above the fire-line, was exploded at a pressure of only 235 pounds—65 pounds less than the same boiler had withstood with Lawson's device, under precisely the same circumstances, except as to the quantity of water.

This discovery and invention remove all obstacles to the use of high pressure. With immunity against explosion higher pressure is safely secured, and with it greater power, and economy attained.

The invention has other advantages of great importance. It produces dry steam, and prevents foaming, priming or entrainment.

With the diaphragm, the steam passes from the lower compartment to the upper, not at one point, but in small quantities at many points; and the steam used being taken from the upper compartment, all the concussive force and intermittent pressure and motion are arrested and confined to the upper compartment, and the result is that the pressure upon the surface of the water is uniform; there is no rising and falling of cone-shaped columns of water, no irregular pressure, no churn-like motion to the water, no irregular and violent ebullition.

With boilers thus constructed, incrustation is wholly prevented. All foreign solid substances held in suspension or solution are separated from the water and deposited upon the diaphragm, where they do not interfere with the generation of steam, and whence they can be readily removed.

Thus, the mystery of boiler explosions having been solved, and a perfect preventive devised, accompanied by the attainment of dry steam, absence of incrustation, and safety with high pressure, are we not upon the threshold of a new era in the use of steam?

Hollow Steel Shafting, which has come very generally into use in Europe, even for such heavy work as steamship propeller shafts, is found to very much lessen the weight in proportion to the decreased strength. It appears, for example, that a 10-inch shaft, with a hole 4 inches in diameter, has its weight reduced 16 per cent, with a loss of only 2.56 per cent of strength.