BOILER EXPLOSIONS.

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In considering the subject of Boiler Explosions, I am aware that it has heretofore received the attention of many able theorists and mechanical engineers who do not agree in their conclusions. That such diversity of opinion exists, is natural from the various conditions of the matter discussed.

What is here prepared may not be new, but the subject is of such vast importance, that even repetition may be pardonable.

If we for a moment consider the field, we find that its extension precludes comprehending the whole in one short paper, which covers the subject proportionally, as the hand might cover a table. That the astonishing developments, attained by the use of steam in the various industries throughout the country, must be ascribed to its universal success as a moderately cheap prime mover none can deny; and the facility with which it can be employed in any section of the land enables the manufacturer to locate his mills wherever desirable, and then transport to them the motive power.

Without it, he must be content with the water courses wherever they may be found, and ever after transport the material of manufacture to and from the market.

Without it many of our large cities and manufacturing centers could not exist to-day. Only while it is considered less dangerous or less expensive than other agents, can steam maintain its now prominent position of principal motive power for nearly all branches of manufacture, transportation, etc.

There are considerations in connection with the present methods of utilizing steam, which, looked upon from every point, would indicate clearly that we are justified by no means in accepting it as the most economical prime mover obtainable. Many unsuc-

cessful attempts have been made to discover a substitute for steam as a source of power, there always having been found insurmountable obstacles, inseparably connected with the use of all other agents; difficulties which science and the best mechanical skill have failed to overcome. Quite a number of years will probably yet elapse, ere these hindrances are pushed aside by the spirit of investigation and invention which pervades the age in all civilized countries. But supposing the successful employment of a more suitable and economical motor might be rendered practicable, during the coming week, month or year, the expense necessary to secure the change would preclude its rapid adoption by many using the present devices. It would in fact be so long before the present arrangements could be superseded that it must still be worth our time to strive for improvements in the manner of employing the power we now have, and to gain some knowledge in which direction, further improvement in its safe and economical use may tend.

Practical experience has taught us, in the past twenty-five years, that there was no economy in the "old time practice" of using steam at a low temperature and pressure for all purposes. The direct advantages accruing from its use at high pressure, securing high piston speeds, and expanding the steam to nearly zero, have been very large. This change came gradually. Many improvements were necessitated, but now the six to fifteen pound pressures of forty-five years ago, and large unsightly engines are supplanted by pressures of fifty to two hundred pounds, and engines of half the size which give the same equivalent of work. As the economy of the higher temperatures becomes generally appreciated, the greater the demand will be for them.

The principal impediment still existing to progress in this direction is due to the limited strength of the present forms of the steam generators. The boilers of the future must be improved so that safety may be insured, being either constructed in sections, or of material with greater strength, also not complicated in design and of moderate cost. That the most important of these requirements have not been realized, is only too apparent from the many accidents continually occurring in different sec-

tions of the country. That some boilers will explode is perhaps inevitable. The increase in the number of those accidents is, in a measure, owing to the increase of the number of boilers in use, and to the greater demand made of them in sustaining high pressure. The inference is plain, that improvements in manufacture have not kept pace with this demand. That all boiler explosions are due directly to the inability of the vessel to retain the enormous pressure generated just prior to the rupture, all will admit, but indirectly there are many primary causes traceable. Of the vast number of boilers in use, but comparatively few explode; fortunately they are the exceptions. Something certainly enters into the conditions where explosions occur different from those in which they do not. Boilers are in use under so many varying circumstances, that two explosions are seldom traceable to exactly the same causes. Instances are known where boilers have been in constant use tor twenty years, and almost without repairs, while others fail in as many weeks or months. This difference must be due to material, workmanship, quality of water, and the attention they receive. We know that certain causes produce certain effects, and that neglect and carelessness have no business in mechanical matters at all, much less should they be seen about our steam generators. It is simply astounding to know the extent to which ignorance and incapacity are placed in charge of these agents of the public service, which, in the hands of incompetent men, are about as dangerous as a package of dynamite. That all boiler explosions are due to carelessness and ignorance we do not mean to assert, but that about nine-tenths of them are, is beyond question.

People are accustomed to think that any thing constructed of iron should "endure forever," merely because made of iron. Well, such an hypothesis may answer in some cases. Experience in the past year alone, however, has taught us, that it is an exceeding unsafe one in connection with steam boilers. That so many incompetent men are found in charge of so many boilers and engines, is principally owing to the fact that they are cheap. Cheapness seems to be the only required qualification. The scale balances up and down like the beam of a steelyard, intelligence and

suitable compensation usually being found at the upper end. Possibly some employers prefer this class of help lest they might learn some disagreeable truths concerning their steam generators. There is, however, one very important point in this connection which is usually lost sight of. There seems to be an inexorable law in force in these cases as in many others. There is a minimum cost in the management of machinery, which cannot be reduced even by machinery. And if the steam user will employ incompetent labor because it is cheap, then the difference between its cost and that of a higher grade of intelligence must certainly be given to the boiler-maker and machinist by way of repairs, and to the coal dealer for extra fuel, as a skillful fireman will save from five to twenty per cent. over an untrained one. I call to mind a striking illustration of the case, that of a manufacturer in an eastern state, who, though a most successful business man otherwise, possessed a remarkable faculty for utilizing every piece of old iron he could obtain, and the extra work on which, in putting it in suitable condition, always cost him more than the new material. His annual loss from breakage and wear, making no account of time when the machinery was idle, due to the employing of a one dollar man where a two dollar one was required, was at least three times the difference in cost of one or two reliable men. A very common practice, and one most reprehensible withal, is that of employers compelling their engineers and firemen (often these consist of but one man) to do their legitimate work and that of two or three others, frequently being called to distant parts of the building. No man can attend to too many duties well; it is in the nature of things that some will be forgotten, and under these circumstances it is just as likely to be the most important as any other.

Boilers are constructed from a great variety of designs. Those found in more common use are of the locomotive type, and the plain cylinder with closed ends. The material usually is from 1-4 to 3-8 inches thick. As a conductor of heat, iron stands low in the scale, gold being as 1000, copper 898, and iron but 347. Now with iron but 1-4 inch in thickness, a great amount of heat is lost in boilers, owing to the inability to transfer all the heat produced

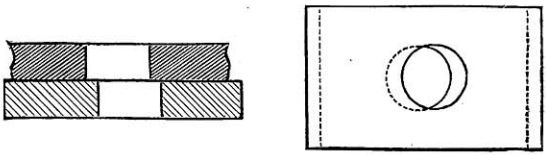
to the water. Hence it is seen we cannot gain security by use of heavier material without a sacrifice of fuel. Small boilers, as a rule, are safer than large ones, if built in proportion, as they have a less number of square inches exposed to pressure. Taking a hasty glance at some of the practices in vogue in the construction of boilers, one of the most objectionable features in this as in many other things, is the too general tendency to obtain our goods at a price below a fair market value, and the custom of letlng these contracts to the lowest bidder often works to the disadvantage of both parties. In this business, of all others, the custom should be discontinued. It is fair to assume that boiler makers are as fallible as any other class of business men. Men do not do business for nothing, as a rule, neither for pleasure. "Each trade has its trick," and the purchasing party who obtains his boiler for less than the market rate, may seek consolation in the fact that he has been "sold" somewhere in his purchase.

In my own experience, I have known boilers constructed under these conditions of so poor material, that the plates did not have the manufacturers' brand on their surface. It may not be out of place to add that the builders of those boilers have had no less than four explosions of boilers of their construction in the past five years. From the time the boiler material is placed in the hands of the workman, it is constantly growing weaker, until thrown aside as old iron. The width of the iron in common use is three feet. Along each edge and across the ends, holes are cut or punched for rivets, after which the sheets are rolled to an approximation of a cylinder. When these cylinders are slipped together, all of the rivet holes should coincide. That they do not is a source of much trouble. The positions of these holes are marked through a wooden templet, which will be about three inches wide by 1-2 in thickness, and of such length as each particular case may require. Along the edges of this templet holes are bored, one set answering for the inside cylinder and the other for the outside. In spacing these holes, about six times the thickness of iron is allowed for difference in length, and the same number of holes must appear in each sheet, only in the short ones they are nearer together. The operation of punching the

holes is a rather haphazard one at best, so far as accuracy is concerned.

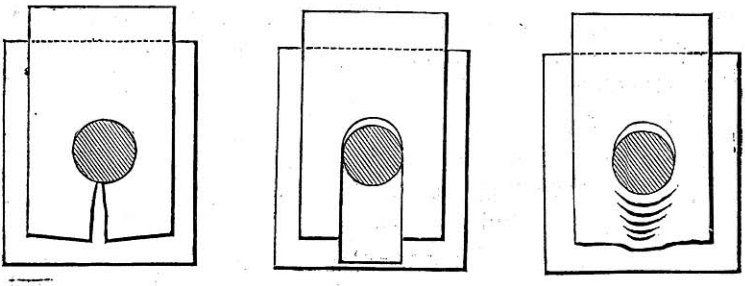
There are two chances for error by the time the plates are rolled. First. The holes will not all be made exactly where marked; if one whole is punched slightly one side of its mark, and the one which it should match the other way, the error is

Fig. 1.



multiplied. Moreover, it is quite impossible to produce these plates and have them perfectly homogeneous. There will be hard and soft places. The great pressure from the rolls in making the plates cylindrical will cause changes in distance between some of the holes, as the temper of the plate varies. When the cylinders are placed together for riveting, many holes will shut past

Fig. 2. *Fig.* 3. *Fig.* 4.

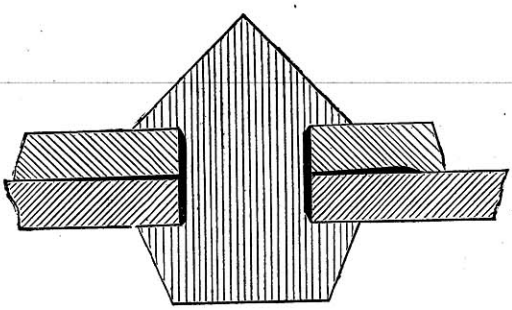


one another from 1-16 of an inch to 1-2 or 2-3 their diameter. This, in itself, is objectionable enough, but the case is aggravated. The overlapping metal should all be removed by the reamer and the hole filled by a suitable rivet. If the overlapping of the holes is not such as to compel the use of the reamer, a most objectionable resort is the tool known in shop parlance as a "drift pin," which is nothing more than a steel pin, slightly tapering, and when well oiled can be driven in with such force that the solid iron is

often compressed and cracked, and pieces of the plate may be forced out. Fig. 1 is intended to illustrate the overlapping holes, and figs, 2, 3 and 4 the effects of the use of the "drift pin." Another difficulty here presents itself, arising chiefly from carelessness and poor workmanship. Often the sheets do not come in contact, and especially at the heads or ends of the boilers, on which the flanges are turned, is this the case, and also on internal fire-box work. When the rivets are driven, the iron acts as a spring, and vibrates back and forth from the blows of the hammer. The rivets too, will "upset" in between the plates if much apart.

Rivets driven in this way can never be made tight, neither will the caulking chisel remedy the defect, for when the caulking is done, the iron is driven back between the plates forming a thin narrow ridge under which the pressure will soon force the water or steam, Fig. 5, is a fair illustration of the case.

Fig. 5.



To this defect are due, many of the mysterious leaks in new boilers, when but a short time in use. Often rivets are improperly supported or "backed" when being riveted, which causes leaks; or riveted when too cold, causing crystalization to such an extent that often a slight jar will cause the heads to drop off. The outer corner of the outside cylinder must be chamfered to an angle of about fifteen degrees, thus leaving a sharp edge where the cylinders join, for caulking. In many large shops this is done by machinery before the plates are rolled, in others before the cylinders are placed together. In many, it is done after the riveting, and thus the lower sheet is more or less cut by the corner of the chisel, the greatest care cannot prevent it. With many boiler-makers, this is of minor consideration, but the fact that many exploded boilers have given way at this point should draw attention to it. The following account of an experiment made at

the University machine shop shows well the effect of cutting through the outside of the iron. A piece of common five-eighths square iron was cut on the four sides with a cold chisel, so that it was well marked. A slight blow from the hammer caused it to break, the ends showing crystalization. A second piece was marked on but one side, which on being broken, was crystalized about half through, the rest showing the fibre undisturbed, and tearing out the iron for half an inch up the bar. It has been claimed that the principal strength of iron is destroyed by cutting through the "skin," yet, a piece of this same bar marked as in the first instance, was placed in the lathe and the marks turned out, after which it was bent to more than ninety degrees before breaking.

It is estimated that about forty-four per cent. of the original strength of the material has been destroyed by the time a boiler is ready for riveting. The axiom that the "strength of any structure must be estimated from the weakest point," is a good one. By these various operations, six per cent. more will be of questionable value. Repeat them at every joint in a boiler twelve to twenty-four feet long, and who will tell where the weakest point may be? Imagine if you can a boiler so constructed of any flexible material, it would contain more kinks and puckers and gathers than a fashionable dress. New boilers are often submitted to the hydraulic test, which consists of forcing in cold water to a certain pressure, and then assuming it safe to carry one-third or two-thirds as much steam pressure. I believe it a questionable method and an unsafe assumption. If there are blisters or imperfect welds in the plates it may develop them. A careful inspection would probably accomplish the same result. But in these tests the boiler is subjected to strains under conditions which do not occur in actual use. The water and iron are both cold, stay rods and braces are loosened which do not again come tight of their own accord. Further, most boiler iron, as demonstrated by the experiments of the Franklin Institute Committee and Fairbairn, a noted English mechanical engineer, has a greater tensile strength with an elevation of temperature, some proving stronger at 600° Fahrenheit, than at any lower point. Now it is quite certain that

testing with cold water has not rendered the weakest point of the vessel much stronger.

As soon as a boiler is in use, the agents of destruction incident thereto begin their work. Probably chief among these, is the steam itself. The unit of elasticity, by which the expansive force of elastic fluids is measured, is for popular use, one pound on one square inch of surface. We glance at a steam guage and the little hand may indicate fifty. Let us ascertain what that means. If a boiler is twelve feet long and three feet in diameter (very common dimensions) and contains thirty-four three inch tubes, the two heads with tube surface deducted have remaining 1,864 square inches. The cylinder of the boiler contains 16,280, equaling in all 18,150 square inches which, multiplied by fifty pounds pressure, give a total of nearly one million pounds, or a fraction over 450 tons, continually tending to rend the cylinder. Boilers are made round or approximately so, for two reasons. It is the cheaper form and one naturally self-supporting. I say approximately round, for they are not a true circle and cannot be made so owing to the lap of the longitudinal seams. Now this enormous pressure, tends to force the shell of the boiler to a true circle. The pressure is never constant. Great and unequal strains are produced along the under edge of the lap, which vary from time to time according to the different degree of pressure. In effect it is similar to bending a piece of iron back and forth in the hands, only on a more minute scale. In time the same result will be effected, destruction of the fibre of the iron.

Many purchasers of these steam generators commit the serious mistake of selecting boilers of insufficient capacity, simply because one or two hundred dollars cheaper. In so doing, the door is opened through which many dollars will pass in the way of fuel without an adequate return. But when a boiler has just the capacity to supply the demand by forcing the fires, a nearly full opening of all passages to the engine will result. The steam flows rapidly through them, twice at every revolution of the engine, this flow is suddenly and positively checked. While so checked, there is a rapid accumulation of steam from the forced fires. The boiler expands to the greatest limit in retaining the increasing

pressure. The opening of the passage way again affords a temporary relief. Thus the boiler dilates and contracts to such an extent that the movements are sometimes visible to the eye, and they have been compared to the breathing of some large animal.

With this slow and continuous change, there is no wonder that boilers eventually "give out." If there is any mystery in the case, it is that they last so long and serve so well as they do.

That steam and water in pipes not properly drained have great percussive action, may be readily seen from the jumping and snapping of the pipes under these conditions, and many serious accidents have occured from pipes and fittings bursting, even loss of life resulting in some cases. With these facts before us, great care should be exercised, not to open the steam passages from the boiler, too suddenly, on account of the danger arising from relieving the pressure on the water.

What effect might be caused by such lack of care, may be seen in the following deduction.

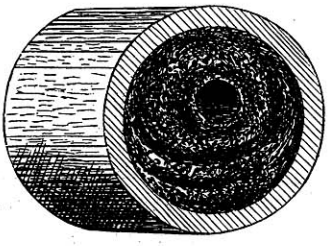
The heat required to raise one pound of water through one degree of temperature is termed a unit of heat, or its equivalent, 100 pounds of water through one-tenth of a degree, or one-tenth of a pound through 100 degrees. This quantity of heat possesses the same amount of power as would be required to raise 772 pounds, one foot, or one pound 772 feet. This is termed the mechanical equivalent of heat. Now if the addition of one degree of heat to one pound of water, be such an accession of force, the addition of 100 degrees to 500 pounds of water is an equivalent of a half million times that force. In practice, the combustion of a pound of coal imparts to the water in a good boiler about 10,000 units of heat, and evaporates eight or nine pounds of water of usual temperature. With all the losses and disadvantages considered, a pound of coal exerts about one-fourth of a horse power per hour, fifteen horse power for a minute or 900 for one second. The heat absorbed by 5,000 pounds of water in raising it through 100 degrees, is really twelve and a half horse power for an hour, 750 for a minute or 45,000 horse power for a second. The amount of heat absorbed by 5,000 pounds of water in raising it through 100 degrees, is but a small portion of the

quantity in any boiler in common use, yet fifty pounds of coal are required to cause it, and the imparted heat is equal to the amount expended to convert about 430 pounds of water at common temperature to steam. By a too sudden release of pressure, this latent heat might all be released in one or two seconds, and thereby cause an explosion. The idea quite generally prevails that all boiler explosions are due to low water. That might cause such a disaster, but that alone I think seldom does. Often, no doubt, boilers are seriously injured by the plates being burned. Burned plates lose about one-half their strength. Repeat the operation often enough and it is only a question of time, and a rather limited time, too, when the boiler will be ruined.

Several years since, the United States government squandered about $100,000 at Sandy Hook and Pittsburg, trying to determine the cause of boiler explosions. The experiments were under conditions which were almost totally different from those under which boilers are used. Hence, practically, they were nearly failures. Two things were discovered, however; one, that a boiler will not explode when you want it to, and that water, pumped in on plates red hot, would all run out through the seams, which were caused to open from the rapid contraction, or else escape through the safety valve as steam. This operation was repeated three times to produce an explosion.

Boiler plates are burned oftener from incrustation than from low water. Wherever this formation is thick enough to prevent the water from coming in close contact with the iron, that must be the result, and if from this cause the plates when in use become sufficiently hot to weaken the tensile strength in a place of any large area, a rupture will surely follow. Fig. 6 shows a section of a feed pipe filled with lime in the short space of three months. A few years since I had an opportunity to examine a case of this kind. The boiler was of the locomotive type, and was not under cover. The plate over the fire had been forced

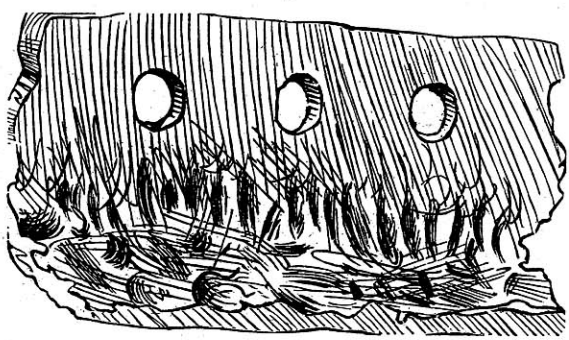
Fig. 6.



down gradually, and in shape like the bottom of a wash-bowl, becoming thinner at the lowest point until finally breaking open, it left rough, ragged edges and a hole about eight inches in diameter. The whole weight of three and a half tons was raised about thirty feet and thrown over back, striking the ground at an angle of about thirty degrees, and sliding along, tore off every particle of the engine.

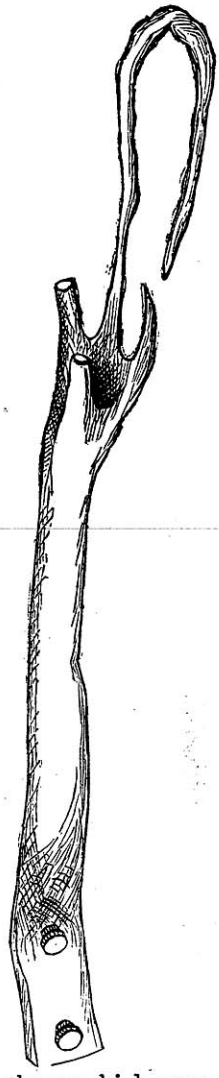
These deposits in boilers are the most difficult matters steam users have to contend with, but its formation to a dangerous thickness can be prevented by frequent cleaning out, also by frequently letting out a little water through the day when the boiler is under pressure. It is a bad practice, and, of course, a common one, to let the water all blow out of the boiler, after the fires are out and before sufficiently cooled. The heat retained in the metal and

Fig. 7.



surrounding walls will cause the deposit to bake to the iron so that nothing less than a hammer and chisel will remove it. Care should be exercised in setting boilers so that they may be examined at different times, and to keep them in places as dry as possible. Iron wastes away fast enough at best, and if leaks occur where the boiler is in contact with brick and mortar, corrosion goes on so rapidly that the best boilers may be rendered unsafe in a year or two. When leaks are discovered they should be considered signs of wearing out, and should receive attention at once. Usually, however, because it is small or does not let out the water faster than it can be replaced, it is allowed to go. It is treading on a dangerous path.

Fig. 8.



Often, when very impure water is used, boilers are attacked by internal corrosion. Usually it is found at the edge of the sheets, along the seams and around the rivet heads. Sometimes different plates in the boiler will be corroded, while others will be found in good condition.

With all this evidence of the dangerous processes going on both without and within a boiler, it seems very plainly indicated, that too much care and attention cannot be given them. Marine boilers are of the most dangerous class, but they seldom explode. The reason is evident. First-class men, and none others, are placed in charge of them. The statistics show that in the decade from 1865 to 1875, there was an average of about one explosion every three days, and it would seem that the public had the right to demand some system whereby a little higher grade of intelligence could be placed in charge of these, now, indispensable agents of the public service.

From the use of impure water results a process called "pitting." Small holes quite near together are eaten into the plates, and often a pitted plate and a sound one will be found side by side. This is probably due to a chemical difference in the iron, and the pitting may be caused by galvanic action. Pitted plates resemble very much the partly consumed zincs from a battery. Experiments were made with pieces of iron cut from pitted plates, and those which were not, taken from the same boiler and placed in a bath of acidulated water, when connected with a galvanometer, the pieces excited sufficient action to sensibly deflect the needle.

Fig. 7 * shows a case of pitting, and fig. 8 represents a corroded brace or stay rod, so much of which is destroyed that it became entirely useless.

* Figs. 7 and 8 are taken from Reports of Hartford Boiler Insurance Company.