the stern-post. The action appears strange and somewhat unmechanical at first, but it is, in reality, quite sound. It will also be seen that there is no stern frame, in the ordinary acceptation of the term, to this boat. There is only one stern-post, the place of the forward post being taken by the two armed depending brackets before mentioned. An incidental, but still important, advantage of this arrangement that must be mentioned is the great ease with which the rudder may be unshipped. By simply taking off one nut and removing the tiller, the whole can be lowered clear.

The whole construction must be one of extraordinary strength. During the run on which we recently had the opportunity of being present, several circles were made at full speed, or, at any rate, what must have been very little short of it. The helm was put over at once, as fast as the powerful steam gear would work it, either to port or starboard. The result was remarkable, not to say startling. The enormous rudder area would at once throw the stern round, and the great column of water we have described would rise up aft, the boat would heel inward somewhat, and the circle was completed in a marvelously short space of time. The most extraordinary thing, however, was to stand right aft and look at the surface of the water near the boat's side. Looking inward toward the circle, there was, immediately against the boat's skin, a narrow stream of water running aft with immense rapidity. The outer edge of this stream was clearly defined, and beyond it the water could be seen, following the stern as it swung round, in streamlines at right angles to the stream of water that was running aft. This vessel, in turning ahead, appears to pivot more toward the bow than any craft we remember to have seen. The heeling inward, we understand, will be able to be remedied before the boat is put in commission, although it seems hardly reasonable to expect that any craft can turn at such a speed and in such small circles without a considerable heeling effect being set up.

In going astern the action was not so remarkable in appearance, although it was, perhaps, more so in effect. Mr. Yarrow seemed to have no hesitation in jamming the helm hard over when steaming full speed astern, and the circles made were certainly smaller than those formed with headway on the boat. In this case, however, although there was a fine spume at the rudder, the water did not present the same remarkable appearance at the side as that which we have attempted to describe. Going astern, the boat seemed to pivot about the center, so that neither the bow nor stern was swinging so violently round.

The vibration of No. 79, when running at full speed was slight, and, no doubt, this may largely be attributed to the three-crank engine. Messrs. Yarrow have devised an ingenious apparatus for automatically recording the number and amplitude of vibrations made by a vessel running at speed; but before the records of this instrument can be of use, except to Messrs. Yarrow themselves for trial among their own craft, a universal standard of comparison would have to be formed. The arrangement consists of a revolving drum worked by clockwork, and round this is wound a continuous paper. Against the paper a pencil is pressed, the latter being attached to a weight suspended by India rubber springs, and free to reciprocate vertically as it would be actuated by the vibrations set up.

Altogether, there is no doubt that Messrs. Yarrow & Co. have produced a very successful boat. They have combined speed and steering power in a very remarkable degree, to say nothing of the strength of construction that enables the stern to stand the heavy strains that must be put upon it by the very large rudder. The absence of dead wood is, of course, by no means a novelty; in fact, this same firm built some boats possessing this feature about six years ago, and, as our readers are aware, another firm engaged in the construction of small fast vessels have made this a special feature in their design.

The boat we have described will be naturally compared with the two Austrian boats, Falke and Adler, but these were larger craft, and naturally got a higher speed, viz., 22½ knots with 17 tons on board, and 24 knots with 8 tons. Messrs. Yarrow have recently received a copy of the official report of the officer who was in charge of the Falke during the voyage from London to Pola. In view of the attention attracted by the unprecedentedly large loco-marine boiler of that vessel, it may be interesting to state that there was no trouble from priming or otherwise during the voyage, and that the total amount of fresh water required for "make up" was one ton.—*Engineering*.

SIBLEY COLLEGE LECTURES.—1886-87.

BY THE CORNELL UNIVERSITY NON-RESIDENT LECTURERS IN MECHANICAL ENGINEERING.

IV.—STEAM BOILER EXPLOSIONS.

By J. M. ALLEN, of Hartford, Conn.

It was my privilege nearly one year ago to speak in this hall on the subject of steam boilers, their construction and management, with a view to safety and economy. The importance of proper construction and management is forced upon us almost daily, by the accounts of steam boiler explosions, often attended with great loss of property and life. During the six years ending January 1, 1886, there were 992 boiler explosions in this country, by which more than 1,500 persons were killed, and many more injured. A large amount of property was destroyed and damaged, besides the loss resulting from delays in rebuilding and replacing boilers and machinery destroyed or rendered useless. These figures are taken from a record which has been kept for many years in the office of the company with which I am connected. They are gathered through our agents in all parts of the country, also from the daily papers. The list may not contain every case of a ruptured or exploded boiler, but it is perhaps as near correct as any such list could be made. The loss or damage to the owners of these mills or works can be only roughly estimated. In some cases it has amounted to \$10,000 and even \$20,000, while in others it would be covered by a few hundred dollars.

If we assume an average of \$3,000 in each case, it gives a grand total of about \$3,000,000. These facts are of sufficient importance to lead to earnest inquiry and investigation into the cause of these frightful accidents. The importance of such investigations was recognized

more than fifty years ago. The whole subject was shrouded in mystery, and some of the theories put forth were laughable. One of the earliest was that all boilers were exploded by electricity. This theory is said to have become popular in this country more than fifty years ago, from the explosion of a locomotive on the Baltimore and Ohio Railroad during a thunder storm. It was asserted that it was struck by lightning. Subsequently, another exploded on a clear day, but as the subject of boiler explosions had at that time been little studied, and as there seemed to be no ready explanation, it was assigned to the same cause. About this time, at the request of the Treasury Department of the United States, the Franklin Institute, of Philadelphia, instituted a series of experiments to test the truth or falsity of the various causes assigned for the explosion of steam boilers. Before speaking of the experiments of the Franklin Institute, I will say a word about the theory of explosions from electricity. Some forty years ago, in England, a locomotive at rest was found to emit brilliant sparks while the safety valve was blowing. This was thought by some to be conclusive evidence that electricity was stored up in a boiler under pressure, and that, under certain conditions, it might act with explosive results. This led to a careful investigation of the subject by men of high scientific attainments. The result was that the presence of electricity in a jet of steam issuing from an orifice was not due to free electricity within the boiler, but to the friction of the escaping steam upon the inner surfaces of the discharging channel.

If electricity should be developed in a steam boiler by ebullition, or in steam when confined under pressure in an iron boiler in perfect electric communication with the earth, it could not be collected, but would be immediately conveyed away. Prof. Faraday investigated this matter, and his conclusions were:

1st. "The production of electricity is not due to any change in the state of the liquid contained in the boiler."

2d. "A current of dry steam produces no development of electricity. The production of electricity is due to the friction in the nozzle of the drops of water formed by the partial condensation of the steam."

3d. "Increasing the pressure of the steam increased the development of electricity by increasing the friction of the issuing jets of steam and water."

4th. "The same results were obtained from compressed air, discharged through the boxwood nozzles, as from steam discharged under the same circumstances. When the air was perfectly dry, there was no development of electricity; when the air was humid, and contained, besides, a very little pulverulent matter, the friction of discharge produced electricity in the same manner as when steam was employed in the experiments."

The boiler which was used in these experiments was insulated on glass supports or legs, and yet the experiments under these most favorable conditions conclusively showed that electricity could not be counted among the causes of boiler explosions.

To return to the experiments of the Franklin Institute. Among the causes of boiler explosions to be investigated were the following: 1st. That injecting water into a boiler in which there was no water, but only hot, unsaturated steam. This would be a case of extreme "low water" or no water at all. The theory was, that when water was thus injected into a boiler containing hot and unsaturated steam, the water would immediately flash into steam of lower temperature, but of sufficient pressure to rend the boiler in pieces. Without going through with this experiment in detail, I will simply give their conclusions, which are as follows: *

"We see that in no case was an increase of elasticity produced by injecting water into hot and unsaturated steam, but the reverse; and in general that the greater the quantity of water thus introduced, the more considerable was the diminution in the elasticity of the steam." There is a very prevalent opinion that injecting water into a hot boiler in which the water has been allowed to get very low is a fruitful cause of boiler explosions.

This is called the "low water theory." It is maintained that the water, coming in contact with hot plates, suddenly flashes into steam of great pressure. Assuming that the severe overheating of the plates has taken place, and water is suddenly thrown upon them, there is reason to believe from the foregoing that the steam disengaged would not be sufficient to greatly increase the pressure already in the boiler. We know that plunging a mass of red hot iron into three or four times its weight of cold water disengages comparatively little steam, and there is no good reason for believing that any more steam would be disengaged if the iron were disposed of in the form of a boiler, and heated to the same temperature. But there are other arguments against this theory. If I remember correctly, a government commission was appointed in 1873 to make some experiments with a view to ascertain the cause of boiler explosions. Among those experiments was one bearing upon this theory. They injected water into an overheated or hot boiler. The result was, contorted plates, leaky seams, and a general demoralization of the boiler, but no explosion.† It must not be inferred from this that no damage arises to a boiler that has been overheated from low water, nor that after such an experience a boiler is suitable for use. On the contrary, it may have been so strained and weakened as to be totally unfit for use at any pressure. I have no doubt that this has been the indirect cause of many boiler explosions. The engineer or fireman allows the water to get low—very low; the plates are overheated and weakened, the strength of the iron is greatly reduced, but instead of drawing the fires and ascertaining what damage is done, he immediately starts the pump, and thinks to cover his carelessness by filling the boiler with water. His fires are urged to keep up steam, but the boiler has been so weakened that it is utterly unable to sustain the pressure, and it "gives out" or "lets go," with more or less destructive results. Another cause which had many advocates was investigated by this Franklin Institute Commission, viz., "decomposed steam." This is often called the "gas theory." It is this: The steam coming in contact with

hot iron is decomposed; that is, the hydrogen is set free, which, uniting with a certain portion of oxygen, forms an explosive gas, which is sufficient to account for many of the destructive explosions.

The experiments of the commission extended over several days, and in one or two instances they succeeded in producing a combustible gas. But other experiments proved that this result was due to the packing of the handholes at each end of the experimental boiler. This packing, consisting of cloth and putty, was highly heated, and the cloth mainly disappeared. They further showed, at least satisfied themselves, that when the bottom of the boiler was heated to redness, no hydrogen was liberated by the decomposition of the water injected. Their conclusions were that "water in contact with heated iron in a steam boiler, the surface being in its ordinary state, clean, but not bright, is not decomposed by the metal."

At a meeting of the American Academy of Sciences, in 1877, it was shown that steam could be decomposed by simple heat into the constituent gases of water, viz., hydrogen and oxygen. The apparatus consisted of a flask in which water was heated, a tube conveying the steam to a closed platinum crucible, where it was again heated by a spirit lamp, and a tube which carried thence the superheated steam and the liberated gases to an ordinary pneumatic trough, where the mixed gases were collected in a test tube while the steam was absorbed. The gases thus collected were exploded by a lighted match. But the question arises, Could this or a similar condition of things take place in a steam boiler? In order to produce an explosive gas in a steam boiler, a large portion of the plates inclosing the steam space must be raised to a bright red heat, then the steam must be condensed by the injection of cold water, which must not come in contact with the red-hot plates, for if the plates are cooled down, how is the explosive gas to be ignited? These conditions are hardly supposable in a steam boiler.

The injection of feed water into a red-hot boiler would weaken the plates and joints and very likely produce rupture. This theory has few advocates now among those who have made the subject a study. The opinions of Professors Faraday, Taylor, and Brande go to show that the cause of boiler explosions by the decomposition of steam is without any support whatever. Another theory, which has some advocates, is that known as the deaerated and superheated water theory. It is sometimes known as the Donny theory, because advanced by M. Donny, in 1770. It is this: That water completely deprived of air may be raised to a very high temperature without ebullition, and that under these conditions it has explosive tendencies.

Superheated water would be water heated above the boiling point, due to the pressure on the water at the time, without giving off vapor. If this were possible in a steam boiler, it would be a source of great danger. Many persons have attributed violent and destructive steam boiler explosions to this cause. But we have no evidence whatever that these conditions ever exist in a boiler. The conditions absolutely necessary for the production of superheated water, according to the experiments of Prof. Donny, were: "No portion of the surface of the water can be exposed to the atmosphere or any other vapor or gas." Again, the contact of a solid body or the smallest particle of air or gas is fatal to the success of the experiment; and again, if steam once begins to form, it goes on, and cannot be stopped until the water is all evaporated. These conditions could not exist in a steam boiler. The experiments of Mr. A. Guthrie, formerly United States Supervising Inspector of Steam Boilers, were conclusive in showing that this theory had little or no foundation as a cause of boiler explosions. The results of his experiments were published originally in the *American Artisan*, and can be found in the August *Locomotive*, 1883. I have spent some time in telling you what, in my judgment, are not causes of boiler explosions, and you are no doubt impatient to learn by this time what are some of the causes of these frightful accidents.

A well constructed steam boiler of good material cannot be exploded except by great force. Knowing the quality of the material, the type of boiler, and assuming that it is well constructed, we can easily calculate the force or pressure of steam which it is capable of resisting, and the pressure which would burst such a boiler asunder would be much higher than any pressure which would ever be allowed on such a boiler under the ordinary conditions of use. A boiler explosion under such circumstances would be called an explosion from over-pressure, and such accidents do not occur except from carelessness or oversight in their management. A stop valve may be closed or the safety valve may be inoperative from corrosion or other cause, rendering relief impossible.

The following illustrated cases will show that through carelessness a boiler may be exploded by over-pressure. In a Southern city, the fire sheets of a boiler became weakened, and repairs were necessary. The boiler was connected with another boiler, but a stop valve in the main steam pipe between this boiler and its companion allowed it to be shut off and put out of use for repairs. The boiler was 48 inches in diameter and 31 feet long, with two flues, each 16 inches in diameter and 27 feet long. Each boiler was provided with a safety valve attached to the nozzle on cast iron head of dome. The main steam pipe was also connected with this nozzle. While the men making repairs were at work in the boiler, hot water from the condensed steam that leaked through the stop valve trickled down upon them and greatly annoyed them. To prevent this, one of the men made a pine plug to fit the hole in the nozzle, and drove it in from the inside. When the repairs were completed, the men gathered up their tools and got out of the boiler, entirely forgetting the pine plug. The manhole was put in place, the boiler filled to a proper height with water, and the fire started. The boiler is said to have behaved very strangely. No steam could be raised. But after an hour or two, the top of the dome was raised several hundred feet, and was found a long distance away the following day. Fig. 1 gives a correct view of it when it was found.

This was a case of explosion from over-pressure. The boiler was abundantly strong for the ordinary pressure required, but the only outlet for the steam was securely closed, and the safety valve rendered useless. Another case of explosion from over-pressure occurred in a Western town. There were two boilers set and connected together as shown in the following, Fig. 2.

* See *Journal Franklin Institute*, volume for 1836.

† Prof. Thurston informs me that the commission that made the experiments at Sandy Hook did succeed in exploding a boiler by injecting water into it when the plates were red hot. But very little energy was developed, and it could not be considered as among the causes of destructive boiler explosions. See *SCIENTIFIC AMERICAN*, 1875.

It will be seen that there are stop valves between the domes and the steam drum, on which the safety valve for the two boilers was located. This arrangement was made so that one or both boilers could be used. The owner was warned of the danger of such an

arrangement, and advised to put a safety valve on each of the boilers, as shown in Fig. 3. But he neglected to do so. And one day, after shutting off one boiler, he built a fire under it, forgetting to open the stop valve. There being no escape for the accumulating steam, the boiler was blown in pieces, as shown by the following Figs. 4, 5, and 6. There are no doubt many explosions from over-pressure through carelessness, similar to these cases.

FIG. 1.

Mr. Fairbairn was of the opinion that all boilers exploded from over-pressure, that is, that the pressure used or allowed was greater than the ability of the boiler to withstand. The element of carelessness

and sufficiently strong for the purposes intended, was fractured by this careless and violent usage. The rupture extended into the sheet, and a very destructive explosion followed. The pressure of steam on the boilers at the time was about 80 lb. This shows how important it is to secure men of intelligence and good sense to properly care for boilers under steam.

Another defect is grooving, which arises from a channeling of the plate. This is caused by some strain, generally brought to bear from the uneasy resting of the boiler in its setting. It may arise from strains caused in construction. But it generally appears along the edge of the lap of both horizontal and girth

Plates become overheated and burned, and have little ability left to withstand the pressure within. These are some of the conditions attending the use of boilers; and when I remember how many of these cases there are, the wonder is that more boilers do not rupture and explode. In a horizontal tubular boiler 60 inches diameter and 16 feet long, ready for use, there would be 1,135.91 gallons, or 9,465.8 pounds, of water. When we start the fires under the boiler, the heat is communicated to the water, which rises in temperature until at 212 degrees Fahr. it begins to emit steam from its surface. The steam, however, is formed at the heating surface of the boiler, and forces its way up through the water to its surface. As the fires are continued, this process goes on with great energy, and violent ebullition is the result. If there is no outlet for the steam thus generated, and the safety valve is weighted to say 80 lb., the steam will accumulate in the steam room above the surface of the water, until it reaches a pressure of 80 lb. to the square inch, when it will begin to issue from the safety valve. The temperature of the steam and water at this pressure is 324 degrees Fahr., or 112 degrees above the temperature of steam at atmospheric pressure. The velocity of discharge of steam at this pressure is about 1,450 feet per second, or at the rate of 16 miles a minute, or 960 miles an hour. The pounds of steam discharged per minute per square inch of opening at this pressure would be about 82 pounds, which multiplied by 4.56, the volume of one pound of steam at 80 pounds pressure, will give us 373.92 cubic feet. I give these figures in order to give some adequate idea of the velocity of steam under pressure of 80 pounds. At 100 pounds pressure, its actual velocity of efflux would be not less than 1,600 feet per second. But from investigation, we have good ground for believing that steam alone at this pressure would not be sufficient to cause a disastrous explosion, even if rupture were to occur. Steam cylinders of engines sometimes fail. The steam is nearly at boiler pressure, and the cylinder is usually of cast iron, but the pieces are not thrown violently away. The pressure is immediately released and its force is gone. We must look, then, for some other cause than steam alone for destructive boiler explosions.

To refer again to the boiler with a steam pressure of 80 lb., what are the conditions? We have a boiler 60 inches in diameter under 80 lb. pressure of steam. The quantity of water is 168.17 cubic feet, or 1,135.91 gallons, or 9,465.8 pounds. This water is heated up to a temperature due to the pressure of steam, or 324 degrees Fahr. All this contained heat in excess of 212 degrees is ready to flash into steam if it had the opportunity

FIG. 2.

FIG. 3.

entered into his calculations, but his opinion was that no boiler exploded except from excessive pressure. His experiments were made many years ago, since which time the use of steam power has vastly increased, and with its increase, boiler explosions have increased as well. We have indisputable evidence that boilers, even those which appear to be good boilers, explode with great violence, at ordinary pressures and at comparatively low pressures. When we examine the fragments of such exploded boilers, we rarely fail to find some hidden weakness from corrosion or from some defect in material or in construction. The careless use of the drift pin in the construction of boilers has no doubt been the cause of many accidents. I have been in boiler shops where this instrument was wickedly used. The rivet holes failing to come fair when the plates were brought together, one riding over the other, the drift pin was used to so adjust them that a rivet could be inserted. The drift pin under the blows of an 8 or 10 pound sledge hammer, with a handle four feet long, causes great distress of the material, and if it does not fracture under the treatment, it is fair to assume that a strain is brought to bear which under ordinary steam pressure will be aggravated, until from weakness and utter inability to "hold on" longer, rupture occurs.

Another case of explosion from carelessness is illustrated by the annexed figures.

Fig. 7 shows the boilers as they appeared just before the explosion. The boilers were nearly new, each 54 inches in diameter and 17 feet long. After using them for some months, some changes were made in the steam drum connections, which being completed the boilers were put in use. The manhole plate of one did not fit tightly; probably from some small portions of the old gasket adhering to the seat. Steam issued from the joint, and instead of waiting until the work of the day was over, so that the cause of the leak could be ascertained, two men secured a wrench with a long handle, and endeavored to force the manhole plate on to its seat by screwing down the nut of the bolt that held it in place. They were not successful in

seams. The continued bending back and forth of the metal loosens up the fiber, and opens it to the attack of any impurities that may be in the water. The channels or grooves extend sometimes nearly through the plate; fracture occurs, and disaster is very liable to follow. A boiler originally well constructed and strong may become weak from low water—I mean by this, overheating from low water—and be in a condition inviting rupture or explosion when used under ordinary working steam pressure. The deposits from bad boiler water work great mischief. Their accumulation in the form of scale of greater or less thickness on the plates of boilers is a source of much trouble and danger.

FIG. 4.

FIG. 5.

FIG. 6.

the boiler in pieces and project the broken parts to a great distance. I have always found that the most destructive boiler explosions were those where there was evidence of the usual supply of water. In discussing one of the experiments at Sandy Hook in 1871, Prof. R. H. Thurston presented the following calculations of the

forces from the boiler of higher pressure to that of lower pressure with a velocity and force due to the difference of pressure and volume of water so disturbed. Very destructive explosions have resulted from carelessness of this nature. Photographs of boilers exploded from this cause were also shown. I

the pressure of steam which supplied it. The pressure of steam was about 50 lb. Here we have a case which will be difficult of explanation by any of the "mysterious agency" theories. It certainly was not electricity, nor deaerated water. There were no over-heated plates, hence no place for decomposed steam. But there was an explosion that caused fearful destruction. The heat in this large amount of water became destructively energetic as soon as an opportunity was given it to act. What weakness might have existed in the material I am unable to say, but there was a rupture sufficiently large to change its potential energies into terribly destructive activities. I will add that up to this time we have the record of some thirty explosions of similar vessels. They are always destructive, because the contained water at a high temperature is a reservoir of power which nothing can resist when it is once liberated. Is there any remedy for these terrible accidents? Yes, within certain limits. I say within certain limits, because certain conditions are involved, and first, if the material of which the boiler is constructed is of inferior quality, it can never be considered as safe at the pressures at which boilers in these days are used. A difference of a cent or a cent and a half per pound in the material often decides as to what material shall be used; for the boiler must be built for a certain price. Thus very inferior material often finds its way into boilers. Then there are defects in construction. The drift pin is wickedly used. The work is not properly laid out, and undue strains are brought to bear in different parts of the boiler, which are greatly aggravated when the boiler is subjected to the conditions of use. These defects cannot be detected by visual examination. The boiler is subjected to a cold water test 50 per cent. greater than the pressure required when the boiler is to be put in use. It shows no leaks. But this does not reveal any of the defects which may exist, and which could only be detected by cutting the boiler in pieces. Another source of danger is the tendency to employ cheap and ignorant men to have the care of boilers. Some steam users utterly fail to comprehend the responsible position of an engineer who has charge of the steam plant of a large mill. Some of the cases of explosions which I have cited go to show the ignorance and carelessness of men who are intrusted with these responsible duties, and in this connection I desire to say a word for the competent stationary engineer. He stands before his engine and boilers day after day, watching with care every detail, and upon his efficiency depends to a certain extent the successful operation of the whole plant. The economical use of fuel is, in a great measure, in his hands, provided the boilers are properly constructed, set, and connected. It is economy to employ intelligent men for such responsible duties, and pay them adequately for it. There has been of late an effort made on the part of stationary engineers to organize themselves into associations for the purpose of mutual improvement. It is a movement in the right direction, and so long as such associations are kept free from politics and other disturbing influences, they should be encouraged. Another means by which boiler explosions can be greatly reduced in number is by thorough inspections. These will not prevent carelessness nor some other of the causes which lead to boiler explosions. As I have already said, it is next to impossible to detect the inferior quality of the material when once the boiler is completed and set. But a careful inspection does detect the defects and weakness of such a boiler after it has been put in use, and I have no hesitation in saying that many very destructive explosions have been prevented by careful inspections. To sum up, then, I will repeat what I have often said. Boiler explosions are mainly due to inferior quality of material, faults in type, poor construction, and ignorance and carelessness in management. We must be honest in whatever we do. Money making is the ambition of all or nearly all, but if it is made at the expense of honesty, it brings little comfort. A person once detected in a dishonest trick will find it difficult to gain the confidence of the public afterward.

[The lecture was illustrated by large drawings and numerous photographs.]

ASPHALT MASONRY FOR ENGINE BEDS.

THREE years ago we described to the Society of Civil Engineers a system of bituminous masonry beds, designed to deaden the shocks and annul the vibrations produced by steam engines and other apparatus that are accompanied with a jarring motion. The communication was accepted with a certain amount of curiosity,

FIG. 7.—Showing the relative position of the boilers 2 and 3, the two that exploded, breaking first at the manhole of No. 3. B F, A E, and C G, secondary lines of rupture. K L, dotted lines showing location of brick piers built for the support of the steam drum, upon the mid walls of the setting.

FIG. 8.—Rear view of the part of No. 3 boiler which is shown in Fig. 7.

FIG. 9.

energy stored up in the boiler and of the work done by the liberated forces. The steam boiler referred to weighed 40,000 pounds, and contained about 30,000 pounds of water and 150 pounds of steam in the steam space, all of which had a temperature of 301 degrees Fahr., when, at the moment before the explosion, the steam pressure was 53½ pounds above that of the atmosphere. Prof. Thurston says: "When the explosion took place, the whole mass at once liberated its heat until it had cooled down to the temperature of vapor under the pressure of the atmosphere." I will not follow Prof. Thurston's calculations through, but he concludes that the maximum possible effect by these liberated forces was sufficient, had it acted in one direction, to have thrown the boiler more than five miles high. As it was, with the liberated forces acting in all directions, portions of the boiler were projected from 200 to 400 feet high. You can find this discussion in full in the *Journal of the Franklin Institute* for March, 1872.* I quote this with great satisfaction because it so fully corroborates the views which I have always maintained from the examination of many boilers which have exploded under the conditions common to boilers in use. The question now arises, Why do not all boilers that rupture explode with such violence? It depends upon the locality of the rupture, and its dimensions. If a crack or fracture occurs on the bottom of a boiler and does not extend to any great length, the water will run out no faster than the steam is liberated into the steam space; but a large rupture at or near the bottom of the boiler, sufficiently large to suddenly discharge a large quantity of water, would be followed alike with destructive results. For by this great disturbance in the steam space of the boiler, the disengaging steam from the water, together with the water, would act upon the shell with great force and destructive results.

[The lecturer here displayed photographs of exploded boilers under these conditions.]

Another cause of boiler explosions is the effort to connect boilers under different pressures of steam by opening the stop valve between them. The water

desire now to call your attention to a case that is of special interest as bearing upon the many theories of boiler explosions which have been advanced from time to time. The drawing (Fig. 10) illustrates the explosion of a rotary bleacher, such as are used in paper mills. It was 20 feet long and about 5 feet in diameter.

FIG. 10.

The plate ruptured at the manhole or stock door, and instead of quietly dropping its load, it exploded with great force, entirely demolishing the mill and doing great destruction to life and property. This vessel was 150 feet from the boiler which supplied it with steam. There was no fire near it, and no heat save that due to

mingled with a slight incredulity which was sympathetically disguised.

Every one expressed himself as much interested in the novelty of the process; but there was instinctively a distrust of it, just as there is of everything that clashes with ideas that have been accepted for a long time.

* See especially Trans. Am. Soc. Mech. Engrs., 1884, and *Journ. Frank. Inst.*, Dec., 1884, for Professor Thurston's latest paper on this subject, giving the amount of this stored energy.