Mr. Fowler. precise magnitude it was of course impossible to say; but the grooving itself afforded irrefutable evidence of their existence. Mr. Beaumont had also said that the grooves seemed always to occur when bending had put the material under tensile stress. That, however, was not the case. The stresses which set up the grooving were sometimes alternately compressive and tensile. It was, in fact, the variation in intensity which fretted and deteriorated the material locally. With regard to the stresses to which Mr. Barry had referred, he was discussing the effect of cutting large openings in boiler shells, and he somewhat regretted that that matter had not been dealt with a little more fully. What he meant was, if the calculated stress in a length of the shell equal to the diameter of the manhole, arising from the bursting-pressure were divided over the remainder of the shell in a line passing longitudinally through that diameter, it would only give a stress of 8·6 tons per square inch, whereas, as a matter of fact, the shell had burst, the plates of which that shell was made having been proved subsequently to be capable of bearing a stress of 20·6 tons. His remarks went to show that the distribution of the stress was very irregular, and that close to any large hole there was a very great stress. What the magnitude of that was it was difficult to say, and respecting those manholes he wished to point out that the distribution of the compensating ring was a matter of great importance, as well as the mere quantity of material that was allowed. For instance, had the material in the neck, shown in *Fig. 11*, been crushed down into a flat ring on each side of that opening he had no doubt the shell would not have failed at that particular pressure. The distribution of material was such as really to afford very little help to the part of the boiler-shell immediately surrounding the hole.

Correspondence.

Dr. Emery. Dr. C. E. Emery considered that the Paper clearly and concisely pointed out the principal causes of boiler explosions, and embodied a number of interesting illustrations based on several types of boilers employed in Great Britain. In the United States there had been explosions from similar causes, but few failures had resulted from distortion of the plates, for the reason that the system of internal bracing was in general more thoroughly carried out in detail. When the country had been undeveloped, and iron more expensive, and there had been limited facilities for dealing with heavy plates, it had been exceptional to find plates thicker

Dr. Emery.

than $\frac{5}{16}$ inch about the furnaces and connections, or even in the flat external heads of a boiler, though circular shells had, of course, been proportioned to the strain. The thin plates required necessarily many braces, and although boilers had in some respects grown to be more massive in construction, heavier plates being used even where unnecessary for strength, but simply to provide for corrosion, the system of bracing had been to a large extent continued; and in many cases, although the points of bracing could safely be separated, small difference had been made in practice. In fact, return-tubular boilers with circular shells at the rear, but with fully braced furnaces in a fire-box externally shaped like that of a locomotive boiler, were still extensively used in small harbour vessels and in larger vessels on fresh-water lakes for steam-pressures up to 100 lbs. per square inch.

Again, in the United States few large flues which were subjected to external pressure were constructed without bracing. Circular furnaces stiffened by flanges and corrugations were employed, as a rule, only for marine boilers, and even in circular vertical boilers the inner and outer walls were almost universally braced by stays or screw-sockets as if they had been flat surfaces. In this way thinner fire-plates were used than were possible by the other system, and collapses of such furnaces were unknown. Again, globular ends were used to a smaller extent under compression, as they were not needed except in new forms of boilers rarely duplicated. As a rule, vertical boilers had tubes through the crown-sheet which acted as braces and tied the crown-sheet and the boiler-head together. It was never attempted in America to dispense with the bracing on a comparatively flat head by constructing the boiler of thicker material. The predominating type of land boiler was a simple horizontal cylinder with fire-tubes running the whole length of the lower part of the shell, and with the flat end-plates above the tubes supported by diagonal braces running to the shell at an angle rarely greater than 30° with the axis of the boiler. This system had given no trouble when the braces had been riveted in place through proper ends, as was the general practice, but boilers in which fewer braces had been attached through stiffening angles had in some instances failed.

Angle-bar connections between the heads and shells of boilers, or at the junction of the boiler-shells and drums or flues like those shown in *Figs. 4, 5, 12, 13* and *14*, were practically unknown in the United States. The boiler-head was always flanged to enter the shell, and in applying a drum to a boiler the bottom of the drum was flanged outwards, as in *Fig. 11*, but the flange was

Dr. Emery. made wider and double-riveted to the shell, thereby stiffening the junction and relieving some of the strain incident to a connecting drum as pointed out in the Paper. It was common also to leave the boiler-shell intact beneath the connecting-drum, with the exception of small drain-holes and one larger opening to give access from the drum to the boiler. This latter feature was not a perfect remedy, but showed that weakness at such points had long been known and in a measure provided for. He had always made it a point to insert special braces across such openings, as a little consideration would show that as soon as an opening was cut in a shell for a drum, the balancing pressure parallel to the axis of the drum was furnished by transmitting the pressure on the head through its shell to the boiler-shell, but the component at right angles to it was in no way provided for without distortion unless braces were inserted across the opening, though the heavy flanges referred to, or, in case of a manhole opening, the heavy covering-plate, added some strength. His practice, in the case of a manhole, was always to set the narrow axis longitudinally to the shell, and then to rivet to the outside of the shell a heavy wrought-iron ring, with its outside curved to fit the shell and the inside flat for the joint, so that the greatest thickness of the ring was at the place where it was most needed.

Failures had frequently resulted with thin plates from the consideration that curved surfaces needed no bracing. A curved surface merely transferred the strains imparted to it to the ends of the arcs. If they were not met at those points by resistances equal and opposite, such as would be provided by well-arranged braces equivalent to plates continuing the curved surface, the structure would, at the haunches of the arches, necessarily be out of equilibrium, and would move until the distortion threw the strain upon other parts sufficiently strong to withstand it. For instance, in a wagon-top boiler with internal furnaces, having semi-cylindrical tops and water-legs or water bottoms, the curved tops of the furnaces transmitted the compression to the ends of the arcs; but the pressure tended to force the furnaces as a whole away from the top of the boiler. Such furnaces must therefore be braced to the circular shell above to the same extent as for flat surfaces, that is, in equal horizontal spaces, rather than those measured on the circumference; or the haunches of the arch must be supported by larger braces up to the shell, and the strain from such large braces distributed to the shell by a network of diagonals. Furnaces had been liable to leak at different points from neglect of this principle, and ruptures might have been due to this

Dr. Emery.

cause. Some dangerous explosions had occurred to boilers of this type, in which the rupture had started on the sides near the junction of the upper circular shell with the flat side plates, showing clearly that the cross-bracing, which was perfectly afforded at the bottom by socket-bolts between the furnace and the shell, must be supplemented by cross-braces above the furnace with branched ends extended somewhat above the horizontal diameter of the upper shell. Some failures had resulted from neglect of this principle in vertical boilers. Referring to *Figs. 5* and *13*, it would be seen that, although the crown of the furnace was supported at the centre by the tube, a great portion of the aggregate pressure was transferred by the globular shape to the edges. This downward force could only be met by the corresponding upward force due to the aggregate pressure on the boiler-head above. The force was therefore transmitted downward through the shell of the furnace and the bent flange connection to the plates of the main shell, and upward through them to the boiler-head. If the shell of the furnace and that of the boiler were connected by socket-bolts, as in American practice, no strain would be brought upon the joint at the bottom, but without this there would be considerable bending strain on the annular bottom of the water-leg, particularly for a wide water-space. In a particular boiler of this kind, without the central flue, the crown-sheet of the furnace was of greater diameter than the shell, but was connected to the latter, forming an annular recess from which fire-tubes were run downward in the water-space of the legs. No stay-bolts for the furnace were used in this case, and the inventor supposed that the globular crown-sheet rendered vertical bracing unnecessary. A boiler of this type had exploded, and from leakages that had been reported on the others and the method of failure, Dr. Emery concluded that the difficulty was started in the flat annular surfaces through which the downward forces from the furnace crown were transmitted to and balanced by the upward forces from the head of the boiler.

The failure of a standpipe or water-column of a waterworks could be traced to the same principle. The standpipe was of large diameter for a limited height, to provide storage for ordinary purposes; but the diameter was reduced above like a bottle, or like the furnace and attached smoke flue shown in *Fig. 13*, discarding the outer shell; and the neck extended up 100 feet or more, so that, in case of fire, the pumps could be started more rapidly and a higher pressure secured promptly. The comparatively flat surface around the neck had been strength-

Dr. Emery. ened by a few braces, probably in order to keep the structure in shape and to provide for wind strains, rather than from any complete idea of the hydrostatic principles involved, but the entire bottom had been practically flat, being only stiffened by angle-iron to keep it in shape. This structure had been perfectly stable so long as the water-level was kept below the neck, and it would have been stable for any height of the large column had there been no neck; but when it had been attempted to fill the standpipe to a considerable height above the neck, a rupture had taken place, and the standpipe had fallen and been destroyed, evidently for the reason that the upward pressure on the neck had been sufficient to bend upward the outer portion of the bottom. Only the portion of the bottom equal to and opposite the central pipe had been in equilibrium for the full pressure. The upward lift on the neck due to the higher column had been resisted entirely by the weight of the metal in the pipe, in addition to the forces due to such portion of the weight of the water as could be transferred through the flat bottom to the shell at its edges, so the shell had risen, the bottom had bulged and the whole weight of the column and its contents had been thrown on the rounded end until the pressure had torn the bottom out of the shell and caused the destruction of the structure.

Mr. Isherwood. Mr. B. F. Isherwood, Chief Engineer, United States Navy, remarked that when the explosions of steam-boilers first attracted attention they had been attributed to several imaginative causes, all of which had been based on a supposed sudden and mysterious creation of enormous pressure, akin to the explosion of gunpowder, in the boiler, which no strength of material, propriety of design, or skill of execution, could withstand. Had any of the causes assigned been true, boiler explosions, instead of being the rarity they were, considered with reference to the number of boilers in use, would have been of such common occurrence and so difficult to guard against by any precautions, that the use of steam-power would have had to be abandoned. Instead of this, explosions of boilers, never frequent, had become rarer and rarer by the employment of persons whose intelligence and incessant watchfulness were sufficient to maintain the conditions essential to safety, and needed never occur with any boilers however designed or manufactured, if they were tested at intervals of, say, six months with a pressure of between double and quadruple the pressure to be employed, and if such working-pressure were not exceeded. If, in addition, the proper water-level was maintained in the boiler, no injury of any kind would be sustained by it. A pressure test and

Mr Isherwood.

an examination of any boiler every six months by a competent engineer, combined with the application to it of any of the "pop" safety-valves, the weighting of which could not be tampered with, and supplemented by a careful watching of the "feed" by a reliable attendant, would ensure almost absolute immunity from danger, let the material, design, and workmanship of the boiler be what they might. No other precaution was needed, and none other would be of any avail in their absence.

However faulty might be the design and construction of any boiler, and however inferior its material in tensile strength, if it satisfactorily withstood a test-pressure of between two and four times the pressure under which it was used, it would not explode unless the prescribed working-pressure was sufficiently exceeded. And no matter how great the deterioration of the boiler might be from six months to six months, if it bore the test it would be still strong enough for safety. When it showed signs of yielding under the test the working-pressure must be reduced until the multiple test-pressure could be borne. It was important that the test-pressure should be maintained within the boiler for, say, at least between fifteen and thirty minutes, instead of being released the moment it was reached. A boiler might sustain the momentary pressure and yet yield under the prolonged pressure. The cause was the ductility of the metal of which the boiler was constructed. To stretch the metal was to do work upon it in the way of increasing its length and correspondingly diminishing its cross section which required time, and these processes might be slow or rapid according to conditions, but under all circumstances time was required, which was often considerable if the resisting and the stretching forces were nearly equal. As the stretching proceeded, the metal in the cylindrical shell of a boiler, for example, became thinner and thinner, until it ruptured at last under the stress it had borne at first, without elongation. In an important explosion experiment made many years ago at Sandy Hook, on a large boiler with a rectangular internally-fired shell, by Mr. F. B. Stevens, of Hoboken, the metal of several seams, after a terrific explosion which entirely destroyed the boiler, had been found to be in as good a condition as before the explosion. The rivets and rivet-holes had been intact and quite uninjured, and no metal forming part of the seam had been ruptured. The two plates united by the seam had been, however, entirely separated, some of the rivets sticking into one plate and some into the other, although the rivet-heads had not even been bruised, and the rivets not even bent. The metal of the plates at the seam had stretched

Mr. Isherwood. so much under the stress, without rupture, that the rivet-heads had slipped uninjured through the rivet-holes, which had been sufficiently enlarged by the stretching to pass the rivet-heads, the holes recovering their normal diameter by the elasticity of the metal as soon as the stress ceased.

Elasticity was the first quality of any boiler material, and without it the construction of boilers would be impossible. The strain, notwithstanding that the stress was equal and simultaneously applied in a boiler, was necessarily unequal, some parts having more and some less thrown upon them than intended, by reason of the different rigidities of different pieces of metal, and because parts of the boiler were left under greater tension due to difference of treatment during manufacture than other parts, whereas this kind of tension should be the same for all parts. For example, no two braces or socket-bolts connecting opposite flat plates in a boiler ever had the same tension upon them when the boiler was free of steam- or water-pressure. One brace might be quite slack and the adjacent braces very taut, the latter having to bear more than their share of the strain, and to stretch considerably before the slack braces could be brought into action and made to contribute their share of strength. All other parts of a boiler showed similar inequalities of strain and strength. Only the elasticity of the metal afforded a compensation which at last brought all the parts into action, and enabled a boiler to be worked with safety.

A boiler explosion, in the proper sense of that phrase and distinguished from a boiler rupture, depended on two conditions only, namely, the rapid or slow increase of pressure by means of an elastic fluid beyond the strength of the boiler to sustain it, and the simultaneous yielding of a considerable portion of the boiler shell. There could be no yielding of the shell unless it was too weak to sustain the pressure within it; but if the portion that yielded was sufficiently small, there would only be a rupture of the shell but no explosion. The damage would be local, not general, and the destructiveness of an explosion, other things being equal, would be largely in proportion to the extent of the portions of the shell which simultaneously yielded. The pressure of explosion must be produced by an elastic fluid capable of continuing its action by its expansion after the actual rent in the shell had occurred. A bursting pressure produced by an inelastic fluid, a liquid like water, caused only a rupture of the boiler but not an explosion. This was an important distinction. With the pressure in proper subordination to the strength, the weak

Mr. Isherwood.

boiler was no more liable to explode than the strong one. The only efficacious means, therefore, for the prevention of boiler explosions, were those which ensured that the working steam-pressure should never exceed a certain fraction of the water-test-pressure. As long as that was done there would be no explosions. This immunity from over-pressure could be automatically secured by means of a conical-faced valve which would open, at the pressure to which it was set, instantly to a height that would discharge all the steam the pipe could pass at the given pressure, and would remain open as long as the pressure to which it was set was beneath it. If the area of the pipe were such that it could pass the bulk of the steam that could be obtained at the boiler-pressure by the maximum rate of combustion of the fuel, and if the valve, or the valve-seat, were made of a material which would not adhere or "stick," and if, finally, the valve were placed in a locked box so that it could not be tampered with by the boiler attendant, the means evidently would be complete to render an explosion next to impossible. No common safety-valve could meet these requirements. It would, indeed, open at the pressure to which it was set, but it would not open wide enough to discharge nearly as much steam as the connecting-pipe could pass, so that the boiler-pressure would continue to increase above the limit to which the valve was set. The conditions were, however, met by the "pop" safety-valve, with nickel-plated seat to prevent sticking, of which there were many varieties differing only in details. Such a valve opened at the pressure to which it was set and instantly rose to the height needed for the discharge of all the steam at the boiler-pressure which the connecting pipe could pass, and remained there until the pressure fell, when it closed with but 1 lb. or 2 lbs. per square inch less pressure than the opening pressure. The pressure beneath the "pop" valve for the aggregate of its area when lifted, was a little more than the pressure beneath it for the whole of its area when seated; the two pressures per square inch for the areas of the lifted and of the seated valve being inversely as those areas.

The only manner in which deficiency of water in a boiler could produce rupture or explosion was by the softening of the metal which took place when denuded of water it was exposed to the high temperature of the gases of combustion, whereby its strength was so much reduced that it yielded to the pressure which it had previously withstood. Up to a temperature of about 550° F., the strength of iron and steel slightly increased, but then, as the temperature rose, it rapidly decreased. The specific heat of iron

Mr. Isherwood. and steel also increased rapidly with increase of temperature. On admitting water to a boiler having part of its heating-surface overheated to a greater or less degree owing to absence of water, the water took up the heat from the metal, and the quantity of heat thus absorbed was measured in Fahrenheit units by the product of the number of lbs. of overheated metal cooled into the number of Fahrenheit degrees between its overheated and cooled temperatures, and the mean specific heat of the metal between those temperatures. No steam could be generated from the water admitted until the water had absorbed the number of Fahrenheit units of heat required to raise it from its initial temperature to its temperature under the boiler-pressure; nor until the specific heat of the water was so much greater than the specific heat of the metal, about seven times for high temperatures, that the metal would not furnish heat enough while cooling to produce any steam, so that the steam-pressure would rather fall in the boiler instead of rise by the admission of cold water. To produce a boiler explosion, the statical pressure of the steam within must alone produce the first rent in the shell, and that rent must be comparatively large and made with great suddenness. The other causes were secondary to the first, namely, the effects of steam-room and water-room, producing duration of the steam-pressure upon the moving mass, and thus aggravating its destructive power. An exploded boiler, as soon as a rent was made in the shell, constituted a large rocket, and all the phenomena connected with it could be explained by the application of the laws of natural philosophy. There was nothing mysterious in even the worst cases of boiler explosions; they were all due to the same mechanical causes, and followed the same mechanical laws. They involved nothing that could not be provided against by the precautions recommended if honestly executed.

Mr. Marten. Mr. E. B. Marten considered that the figures given in the Paper, as to the energy stored up in the hot water, were truly described as the only satisfactory basis for investigation of the subject. They were perhaps with difficulty realised by those who had the care of boilers. It had been necessary to take some pains to explain the matter to juries at inquests or to others investigating explosions, and the simple illustration seemed best understood, that the boiler would have kept the works going for a considerable time if the energy had been used properly through the engine, but as it was let loose suddenly it spent its force in destroying the premises. The true and simple causes of boiler explosions, as elucidated by the careful study of their records for a long period, were still

Mr. Marten. tardily accepted by those who had charge of boilers; and mysterious forces, among which electricity was a favourite, because some explosions had happened during thunderstorms, were still put forward to account for them. In a series of models of boiler explosions which had been exhibited in various centres of industry, a hydro-electric boiler had been shown to explain that its electricity was only due to the friction of the partially condensed steam in passing through a wooden orifice, but he feared that when the boiler was seen to emit brilliant sparks from every part, the idea of electricity being a cause of explosion had been rather strengthened than dispelled.

All who had had the care of boiler-inspection on a large scale must have been surprised that some boilers which had been found to be very defective could have worked at all, while others that appeared sound had exploded. As an instance, an old Rastrick boiler had been found to be reduced in places to the thickness of a sixpence, and another had been substituted 2 feet smaller in diameter and working at 20 lbs. per square inch less pressure, and yet the new boiler had burst in a short time and caused much damage. The owner had been much puzzled, as the old boiler had worked safely at a higher pressure, and the new one which burst showed no corrosion, and the plates had borne a high tensile strain. The explanation was simple, as the old plates had been particularly good and tough, and the new plates so hard and brittle that they could not accommodate themselves to the strain of unequal expansion and set up dangerous seam-rips. This unequal expansion had been wisely stated to be a greater strain to many boilers than that from internal pressure. In fact, some boilers had failed from this cause when heated before they had been exposed to pressure. Most of the well-known and favourite types of boiler were the results of long attention and care to provide sufficient accommodation for the unavoidable unequal expansion in such complicated structures.

Mr. Munro. Mr. R. D. Munro observed that the Author, in referring to collapse of furnace-tubes, had stated that the results of such collapses were rarely of so serious a nature, and that he could only remember one case during the last twenty years in which shortness of water led to the destruction of the boiler-shell. He remembered three very serious cases of this nature within the last five years, two of the boilers being of the Lancashire type of maximum size, and one of the Cornish type. He also remembered about six instances of vertical boilers which had been displaced and thrown to considerable distances, owing to collapse of the fire-boxes. The

Mr. Munro. danger of collapse of the furnace being the occasion of serious explosion was one that should be kept prominently before steam-users, as although many collapses occurred without such serious results, the probability was that, with the rise of pressures now so general, disastrous explosions would occur more frequently from this cause. Under the heading of faulty material and construction, reference had been made to the explosion of two boilers, one of the Lancashire type and one of the vertical type, by the Author, who considered that, "in both of these cases a severe hydraulic proof-test would have revealed the defective construction." A severe hydraulic proof-test was seldom recommended by responsible engineers, and it was questionable if even a proof-test of twice the working-pressure would have revealed the defects in the boilers in question. He had every reason to believe that the vertical boiler referred to (the particulars of which he had investigated at the time of the explosion) had been tested repeatedly in the course of its service, and at none of the tests had there been anything to indicate the existence of such a gross and culpable piece of workmanship as that which had caused the explosion. He was astonished that the Author should suggest or even imply that the condition of such important matters as material and construction should be left over to be determined by a hydraulic test. It was well known that such defects as those to which the Author had referred could only be satisfactorily guarded against by inspecting and testing the material where it is manufactured, and thereafter by careful examination of the work whilst the boiler was in process of construction.

Mr. Shaw. Mr. G. H. Shaw desired to ask the Author whether double butt-straps had been tried for the longitudinal seams of locomotive boiler barrels, and if so, whether they had had any effect on the grooving, as it seemed to him that if it was due to the local straining of the plates caused by bending action, the double butt-straps should be the means of its prevention.

Mr. Sheffield. Mr. G. H. Sheffield, referring to the Author's remarks on the grooving of the angle-bar attaching the end plate to the shell, *Fig. 4*, had observed defects of that nature and attributed them to the excessive rigidity of the angle-bar ring. When a boiler, fitted in this way, expanded longitudinally, there was a tendency to force open the angle-bar at the most rigid point, viz., the root of the angle, which resulted in a laminated fracture. The action varied with the pressure and temperature in the boiler. There was no doubt that the support afforded by gusset-stays riveted to the end and circumferential plates was unequally distributed and

Mr. Sheffield.

aggravated the tendency of the angle-bar to groove. For these reasons he advocated flanged ends with large radii and stays, so that the longitudinal expansion was more gradually and evenly distributed than when angle-bar rings and gusset-stays were used. He considered that a single uptake for large vertical boilers was detrimental to their efficiency, inasmuch as the heat of the furnace was concentrated on one point, resulting in uneven evaporation; and furthermore the flanged ring attaching the uptake to the fire-box crown-plate was a source of weakness, as it did not compensate for the material cut out of the fire-box crown-plate, and was subject alternately to excessive tension and compression. Vertical boilers, intended for high pressures, and of more than 4 feet in diameter, should be fitted with through tubes, and the fire-box crown-plate should be attached to the shell crown with vertical stays. This arrangement, of course, necessitated the use of a smoke-box. He endorsed the remarks of the Author on the inadequate circulation around fire-boxes due to defective design, and had already pointed this out in reference to the fire-boxes of locomotive boilers.[1] In large vertical boilers it was not good policy to sharply flange out the base of the fire-box and rivet it direct to the shell, because it was impossible to clean out the so-called foundation-ring; consequently grooving and corrosion were started through the base of the fire-box being filled with a solid deposit. Although the plea of a little extra expense might be set up, yet a solid foundation-ring for large vertical boilers was more consistent with a finished design than riveted angle-bars or flanged plates, and moreover, the base of the fire-box offered ready facilities for cleaning out the boiler.

Mr. Fowler.

Mr. W. H. Fowler, in reply to Dr. Emery's remarks on the defective character of some of the flanged connections illustrated in *Figs. 4*, *5*, *12*, *13*, and *14*, which he stated were practically unknown in the United States, wished to point out that the boilers shown in the *Figs.* referred to should not be taken as at all representative of good English practice, but rather as defective exceptions which, partly as a result of their faults, had eventually resulted in failure.

The bracing of cambered ends in small vertical boilers was frequently adopted, but there was sometimes an objection to these stays in practice, in that they interfered seriously with free access for the purpose of inspection, and it was the freedom of access to

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[1] Minutes of Proceedings Inst. C.E., vol. cix. p. 383.

Mr. Fowler. the interior which largely determined English boiler-makers in land practice to favour gusset- rather than longitudinal bolt-stays in Lancashire and Cornish boilers. Bolt-stays were also used in conjunction with gussets for high pressures, but the flat ends of these boilers as a rule were so strong that the bolt-stays could be dispensed with. Indeed, they were generally regarded as a "stand-by," and left with a fair amount of sag or slack in them so that they were not called upon to bear any serious stress under normal conditions.

Judging from the high boiler-explosion rate which prevailed in the United States as compared with other countries, it would appear that American practice in boiler construction was either defective, or that boilers subsequently received very improper treatment. As far as the Author could learn, the excessive number of failures in America was due to the use of a low factor of safety coupled with the employment of unsuitable material, cast-iron being frequently adopted for the heads of drums, &c., which in this country would be made of wrought-iron or steel. In addition to this the equipment of boilers was often of a defective character, single instead of duplicate water-gauges being used, while the safety-valves were often of defective design and grouped with other fittings on a common opening. Steam-domes and drums were now seldom adopted in English practice, anti-priming pipes, fixed near the crown of the boiler and coupled direct to the outlet for the stop-valve, being found quite as efficient and generally used in preference.

Referring to Mr. Isherwood's remarks as to the comparative scarcity of boiler explosions, it was true the number of these disasters in this country had, during recent years, been greatly reduced. In the United States, however, the number far from diminishing had steadily increased during the ten years ending 1893, a carefully compiled return for that country giving a total of 2,113 explosions, resulting in the deaths of 2,652 persons, or an average of 211 explosions and 265 persons killed per annum. It was difficult to compare these exactly with similar figures for Great Britain, since every mishap or fatality in connection with the working of a steam-boiler plant in this country was investigated and reported on by the Board of Trade; but it was probably understating rather than overstating the case to say that the explosion-rate and resulting death-rate were at the present time ten times as high in America as in this country, although the number of boilers in operation was probably not far from the same in each case. Mr. Isherwood's suggestion as to the adoption

Mr. Fowler. of a hydraulic test every six months of "two to four times" the working load was in the Author's opinion not only unnecessary but open to grave objections. With a factor of safety of six, which was about the limit adopted by English engineers in boiler practice, it was not wise to apply the hydraulic test to more than double the working-pressure even with new work. If a test of four times the working-pressure were applied it would mean that boilers would require to have a factor of safety of twelve to avoid the risk of injury by the test. Such a factor for the pressures now in use would involve exceptional thicknesses. In cylindrical marine boilers, for example, it would mean plates between 2 inches and 3 inches in thickness, which, in turn, would give rise to many difficulties in the working of the boilers from overheating and unequal expansion, &c. Apart, however, from these considerations, English experience showed that a factor of safety of six was ample with anything like ordinary precautions. Mr. Isherwood's statement that however faulty the material or construction of a boiler might be, it could not explode if it successfully withstood such a hydraulic test as suggested, was, in the Author's opinion, not borne out by facts. The hydraulic test was occasionally a valuable supplementary aid to visual inspection, especially as regarded parts which were difficult of access, or whose strength was indeterminate for other reasons. It should not, however, be regarded as a substitute or relied on exclusively. Instances had occurred when boilers had exploded after withstanding a water-test to a much higher pressure than that at which they were worked. The indiscreet application of the hydraulic test to a serious extent might do more harm than good by distressing the material. The test should always be made under skilled supervision and coupled with careful gaugings in order to ascertain that no permanent injury had been done to the structure. The behaviour of the plates in the experimental boiler explosion at Sandy Hook, as described by Mr. Isherwood, was most extraordinary, and nothing approaching it had ever been met with or recorded in the Author's experience in connection with boiler explosions in this country. That the plates in a boiler should be capable of being stressed to the point of rupture, and that the rivet-holes in the seams should become so enlarged as to permit of the rivet-heads "slipping uninjured through the holes," which then "recovered their normal diameter by the elasticity of the metal as soon as the stress ceased," was most remarkable. He had seen many splendid specimens of material used for boiler construction, but never any that would behave in such a manner.

Mr. Fowler. Instances had been recorded in which flat surfaces stayed with screwed studs had been bulged between the stays and the holes enlarged so that they heeled over the slightly riveted end of the stay without damaging the thread; but this was different altogether to the action described by Mr. Isherwood, which was at variance with all experience respecting the behaviour of iron and steel.

These remarks might be taken in a measure as a reply to some of the comments made by Mr. Munro. He did not, however, in the Paper "suggest or imply that the testing of such important matters as material and construction should be left over to be determined by the hydraulic test," as Mr. Munro had stated. On the contrary, in his opinion the material of all boilers should be tested before it was used, while the construction should be carefully examined in progress as well as tested by hydraulic pressure when complete. But in the case of boilers which were already in existence, and the history of which was uncertain, the application of a careful hydraulic test was occasionally a great help to inspection, and sometimes the only means of obtaining information as to the quality of the material and workmanship. It was as illustrations of the value of the test for this latter object that the references to the cases in the Paper were made. With reference to Mr. Munro's remarks regarding the effect of shortness of water, the Author had alluded strictly to boilers of the Lancashire and Cornish type, and he adhered to the statement he had made. He was aware that certain collapses of furnace-tubes had been accompanied with ruptures of the shell, but these had not been simple cases of overheating from shortness of water. There had been many cases of "vertical boilers which had been displaced and thrown a considerable distance owing to the collapse of the fire-boxes." He did not, however, question this or assert anything to the contrary.

The question asked by Mr. Shaw respecting double butt-straps and grooving had been raised and answered in the Paper in reference to grooving in locomotive boilers. The cause of the grooving alluded to in *Fig. 4* had not been the "excessive rigidity of the angle-bar ring," but the unequal incidence of the stress. In this particular case the trouble arose because the angle-ring and the end-plate were too light. He quite agreed, however, that a flanged end well curved at the root was, when it could be adopted, better than an angle-ring attachment. Bolt-stays were better than gussets possibly in some cases, but on the other hand, gussets possessed decided advantages in many instances, and often afforded

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opportunities of access for inspection and cleaning which would be impossible with bolt-stays. The use of bolt-stays in vertical uptake boilers was sometimes necessary, but at the same time it was possible to bind the crown of the fire-box and shell in this class of boiler too rigidly together, and he had met with instances in which the excessive rigidity arising from this cause had given rise to grooving of the uptake. He quite agreed, however, as to the superiority of solid block rings at the base of the water-space in small vertical boilers as compared with the plan of flanging out the base of the fire-box, as shown in the sketches of some of the boilers which had failed. The method of flanging not only reduced the thickness of the material, but in the case of iron plates rendered them more liable to corrosion.