Mr. FLANNERY said Fig. 1 (p. 126) showed graphically that economy did not increase nearly in the same ratio as pressure. The horizontal line at the bottom indicated the pressure along its length, and the curved line the economy in its distance from the horizontal line. It would be seen that the curve became more nearly parallel to the horizontal line as the pressure increased. Diagrams of the "Propontis," "Montana," Perkins, and Circuit Boilers were also shown for the purposes of the discussion.

Mr. E. A. COWPER regretted that the substance of the Paper did not carry out the title, and that no definite construction of boiler had been pointed out as being good, and "adapted for very high pressures;" also that no absolute pressure of steam had been advocated as the right pressure to use. It would appear that the Author intended to treat on the subject of marine boilers; and it was quite necessary to keep the consideration of land and marine boilers separate, as they did not follow the same rules as to weight, power, bulk, floor-space, cost, or even chimney draught. If it was intended to give a history of tubulous boilers and their failures, such well-known boilers as "Spiller's," "Hancock's," "Shand's," "Goldsworthy Gurney's," and others ought to have been described. "Spiller's," for instance, was a very successful boiler, having the water in the tubes, crossing the inside of the fire-box, the tubes being 3 or 3½ inches in diameter, of moderate length, and at an inclination of 3 inches in the foot. It enabled a higher pressure to be carried than had hitherto been used afloat, and worked better than most old boilers of the time, though it had given place to the modern marine boiler, with the fires in long furnaces and return tubes over the furnaces. This boiler with a strong cylindrical shell, and well stayed ends, was an admirable one for marine purposes. The Author had not recommended any one tubulous boiler as a good, practical and safe marine boiler, but had stated that some of the boilers were capable of being modified so as to make them successful. Mr. Cowper thought tubulous boilers that required sheet-iron casings lined with brickwork had better not be sent to sea, for fear they might be shaken to pieces. Tubulous boilers weighing above 30 per cent. more than ordinary marine boilers should not be put on board ship unless great advantages could be proved to be obtainable. Tubulous boilers that primed so seriously on the slightest provocation as to burn out quickly were not safe in ships. Boilers with a mixture of long tubes, some 2½ inches and others 12 inches in diameter, in which the steam and water were so confined that the tubes were burnt out and exploded again and again, were to be noted only for the purpose of avoiding them, as any approach to such incongruous constructions must lead to serious disappointment and loss. It was not a question of adding to this or to that boiler an extra outside return tube to admit water for the heat to act upon, nor of increasing the size of certain narrow necks to confined bottles of water exposed to fire; but it was the question of constructing a boiler without such steam traps and confined spaces, or entailing the necessity of using pure water, that should commend itself to the notice of engineers. He was not one of those who thought that perfection had been attained either in boilers or in engines, nor did he agree with the Author that engines had been attended to to the neglect of boilers; for about one hundred and seventy patents for boilers were taken out yearly, and a great deal of thought and ingenuity had been expended on them, though much labour had been misapplied owing to a want of appreciation of the necessities of the case. This was proved by the drawings exhibited, and by the results of the working of such tubulous boilers. The proper function of a marine boiler was to make a large quantity of steam on a limited area of floor. To work well, it was necessary that the water should have room to allow the bubbles of steam formed on the metal to rise freely. The steam ought not to be kept down by a horizontal covering of metal; it should be allowed free egress from the water, otherwise priming and burning of the boiler would take place, from the steam driving the water before it, thus leaving the metal dry. Horizontal, or nearly horizontal, tubes exposed to a hot fire were particularly objectionable in both these respects, as the water did not give a passage to the steam, and the steam being produced in large volumes, filled the tubes, and drove the water before it, leaving the tubes dry, and there being no medium to keep down the temperature of the tubes, they were quickly burnt or worn out. In some tubulous boilers it was impossible to tell to a foot where the level of the water was; and he had known cases where the stoker did not know whether the water was in the glass gauge or out of it. Such boilers were troublesome to manage and to feed with accuracy. A very hot fire playing at right angles against a plate dominated the temperature of the plate, even if there were plenty of water behind it, and would soon burn the plate. This fact was well known in reference to the use of the waste heat from puddling furnaces. A thin wall of brickwork was commonly put against the plate to receive the impact of the flame, and then when the current of heat had been turned around the boiler, there was no further occasion for a protection of brickwork.

He had often seen these effects, and had known other boilers properly protected work well.

In the management of boilers one point should never be lost sight of, and that was to keep the boiler as nearly as possible at an even temperature. More injury was done to boilers from variations in temperature than was commonly admitted; thus, if the bottom of a boiler was cold whilst the top was hot, very great strains would be brought upon it, particularly if it were a long one. Cases had occurred with double flued Cornish or Lancashire boilers, in which the bottom of the boiler was so cold as to admit of being handled, whilst there was a pressure of steam of 20 lbs. per square inch at the top. A few Galloway tubes were often put in the flues, partly to promote active circulation, which was so important. With regard to the degree of advantage to be obtained theoretically by the use of steam expanded down to a little above a fair vacuum, he did not quite agree with the results as given on the diagram. There was no difficulty in setting out the true expansion curve, as de Pambour's experiments showed the bulk of the steam at given pressures in comparison with the bulk of the water that had produced it; and as the latent and sensible heat together were practically a constant quantity for steam at different pressures, the proportionate bulk of steam at once gave the ordinates of the expansion curve. He had thus set out the true expansion curve in 1849, and his late brother, Mr. Charles Cowper, had then published it.[1] He had proved the truth of the curve again and again. The economy to be effected theoretically could be calculated best from the above expansion curve. By using steam at 125 lbs. per square inch total pressure as against 70 lbs. total pressure, it would be found that an economy of only 21½ per cent. could be gained. This he considered was a poor recompense for the additional trouble, expense and annoyance in reference to joints, valves, pistons, &c., due to using steam of the higher pressure; and if there had to be added a bad boiler, or one difficult to work regularly, he did not think the change would be economical. No practical result had been put before the meeting to justify such a change, as the result obtained for a short time with the "Propontis," viz., that of 1½ lb. of coal per HP., with a pressure of steam of 150 lbs. per square inch, had been far exceeded with a pressure of 55 lbs. of steam from ordinary strong marine boilers.

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[1] *Vide* Institution of Mechanical Engineers Proceedings, 1877, p. 147, and plate 47.

Mr. LONGRIDGE agreed with a great deal of what Mr. Cowper had said, particularly in his conclusions with regard to the advantages of very high-pressure steam. The Author seemed to assume, as a fact admitting of little dispute, that further economy in steam work was to be obtained by the use of very high pressures. So far as the theoretical curve went there was a certain advantage; it did not increase so rapidly when the pressure was increased to a great point; but practically it was well known that the advantages that might be supposed to follow did not accrue, either from the hyperbolical curve or from the real adiabatic curve. Various statements had been made to explain this: that the cylinders absorbed so much heat; that the heat flowed into the condenser, as if it were some independent fluid that ran away wherever it could get, and the like; but he had never seen anything which satisfied him as to the real cause. Again, supposing it to be an advantage to employ a very high pressure, say 200 lbs. or 300 lbs. per square inch, the Author said there were no means, with existing boilers, to obtain it. With a modification of the locomotive type any pressure could be obtained that could be got by the extraordinary boilers described by the Author; 200 or 250 lbs. could be obtained with the greatest safety. As regarded space, weight, and price, a modified form of the locomotive boiler would beat in every respect the boilers referred to. It might be said that in the marine engine there was no steam blast; but nothing was easier than to substitute a bellows or fan blast, which would succeed perfectly; the amount of force required was very small, and combustion could be obtained to any extent desired. The Author had given no details of the cost of the boilers, their bulk, weight, and evaporative effect; and hence he failed to see any great value in the Paper. Certainly, a good description was given of five or six new types of boilers, all of which, however, seemed excessively complicated, and none of which he should like to use. It was stated that in the "Propontis" boiler 1 HP. was obtained from $1\frac{1}{2}$ lb. of coal. One indicated HP. was a very indefinite unit; but allowing all the advantage possible, and supposing that every lb. of coal evaporated 13 lbs. of water, that would give 20 lbs. of water represented by 1 HP. The "Propontis" had an 1,100 HP. boiler; consequently it evaporated 22,000 lbs. of water per hour. The heating surface was 8,700 square feet, and every foot evaporated $\frac{1}{25}$ cubic foot of water per hour. In a recent Paper[1] he had given the results of the evaporation from nineteen locomo-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lii., p. 101.

tives taken indiscriminately, and the average of those was $\frac{1}{8}$ cubic foot evaporated from every square foot of surface; so that the "Propontis" boiler did only a third or a fourth of what an ordinary locomotive boiler could do with great safety and ease. He had no means of checking the other boilers described, but he felt sure, from the proportions given in the table, that the same remarks would apply to them. The advantages claimed for them seemed to him perfectly illusory, and none of them could compensate for the disadvantages in regard to cost, bulk, weight, and economical effect. The Author had stated (p. 129) that "the tendency of these layers of gas, which have parted with their heat, to continue in contact with the plate is very great, and . . . . there is comparatively little opportunity for those layers of gas furthest from the plate, and which have not yet cooled down, to change place and part with their heat in the most direct manner, unless some means of breaking up the current of the flames are interposed." If there were any facts bearing out that opinion he should be glad to hear them. It was a favourite idea of the late Mr. Charles Wye Williams to put things inside the tubes, whirl them round, and so create currents of air; but the results he expected were never obtained. It was, besides, quite contrary to Mr. Longridge's opinion as to the distribution of heat under those circumstances. He believed the heat was radiant, and passed not from particle to particle by conduction; but that it went, like all radiant heat, with enormous velocity from the centre to the circumference. The Author further stated: "The balance of evidence appears to show that higher pressure on the whole facilitates the circulation in a well-designed tubulous boiler." Perhaps he would state where that evidence was to be found. He agreed that there was nothing more important than good circulation. In the Paper to which he had referred there was a constant *m*, the value of which he had assumed to be 7, but he believed by an increased circulation that constant might be nearly doubled. Sir John Leslie, many years ago, showed, with regard to a body cooling in air, that taking the rate of cooling in still air to be unity, by swinging the body round at 60 feet per second the rate of cooling would be increased tenfold. The same law applied to water, and therefore any means of increasing the circulation in boilers would be productive of great advantage.

Mr. RICH wished to call attention to the loss of economy in high pressure boilers in consequence of the greater heat of the gases escaping up the chimney. In any high-pressure boiler the steam, and also the bulk of the water, must necessarily be at a much higher temperature than in a low-pressure boiler. In a boiler under 500 lbs. pressure per square inch the temperature of the steam and of the bulk of the water would be nearly 500°; and instead of the gases escaping in the chimney at a temperature of 350°, as in an average good boiler under 60 lbs. steam, they would escape at 550° to 600°. That extra heat wasted up the chimney was one of the elements which reduced the economy of high pressure boilers.

Mr. SPENCER said, as he was about to put engines and Perkins boilers of 800 HP. in a ship now building, he might be permitted to make a few remarks with reference to the use of boilers on the tubulous principle. He might observe that it was quite impossible to get anything but suggestive Papers on such a subject, as engineers were unwilling to bring their failures into notice. Suggestive Papers, however, were serviceable in bringing out opinions, and perhaps answered better than Papers advocating some particular plans by those whose motives might be suspected, which could certainly not be the case in regard to the present Paper. If the only advantage to be derived was the theoretical gain in economy from doubling the pressure of steam, not much could be urged in favour of very high pressures; but this was only one element among many. It might seem an anomaly, but his opinion was that an increase of pressure was the only road to safety. Many existing defects arose from too low a pressure, and as soon as it was found necessary to use a pressure much beyond that employed in the dangerous boilers now at work, a new era of safety would be arrived at, and a class of boilers would be obtained which would excite no fear of bursting. The great thing to avoid in all steam boilers was the liberation of a large body of water from a large chamber. By reducing the quantity of water to such an extent that in case of the boiler bursting it would simply cause a little vapour to be thrown into a large space without doing injury, a great advance would be made. In very high pressures, it was necessary to use small chambers, and that permitted the use of comparatively thin material. With the existing large boilers it was often necessary to use 1 or $1\frac{1}{4}$ inch plate, and the fire inside and the cold atmosphere outside gave rise to all sorts of contractions and other injuries that destroyed the boiler in a short time. In a Perkins boiler the weakest part required about 12,000 or 13,000 lbs. to the square inch as a bursting pressure; taking the ordinary strength of 20 tons per square inch, there was a large margin to begin with; and therefore if by any accident the feed was irregular, the boiler could be severely strained without danger. He had come to the conclusion that excessive circulation in boilers never occurred except where there was some distortion in the boiler which produced the circulation. A double-ended marine boiler, for instance, with narrow water spaces, and large heating power, was turned into an ejector with a very active circulation, and great destruction to the engine. In the case of a common pot put over the fire what circulation was there? Steam was thrown off at the top, but unless the pot was forced beyond a certain amount the steam would be comparatively dry. The Perkins' boiler was always in a constant state of priming, and yet dryer steam it was impossible to get. He could not explain it, but there was no circulation as the term was generally understood. He was satisfied that any accident like that in the "Montana" was impossible. If the "Montana" had had a better arrangement at the top of the boiler, giving a more regular pressure on the different sections, the accident probably would never have happened. He could not see that there was any possibility of the Perkins boiler going wrong at sea, unless it was allowed to remain red-hot for a long period. He was putting boilers into a yacht of 700 tons, with full sail power, under circumstances most favourable for trying a new system. He should never have thought of introducing the system had he not great faith in it. He believed that the use of very high pressure steam, say 300 or 400 lbs. per square inch, was the only road to safety in marine steam engineering. By some such system as Perkins', with small chambers of moderate thicknesses, and a large surface divided into sections, nine-tenths of the present troubles with steam-boilers on board a man-of-war would be avoided. The small tubular system, however, could not be adopted except on some such plan as Mr. Perkins proposed, with a supply of pure water, a difficulty not so great as it appeared. No internal lubrication could be used with the Perkins system, but the pistons were self-lubricating. To ensure durability, tight joints and pure water were indispensable. It had lately been discovered in France that it was easy to separate the impurities coming from surface condensers before they passed into the feed pipe. That was another step in the right direction.

Mr. Scott Russell remarked that the Paper directed the attention of practical men to a critical point in the history of the steam-engine, and especially the marine engine. He agreed with Mr. Spencer that the present state of marine boilers was extremely dangerous. He also agreed that safety for the future was only to be secured by going in for very high pressure, with all its advantages, and taking precautions against its dangers. With high pressure, a boiler could be used of a given power, of much less bulk, and of much less weight. The dangers attending it were priming and scale. With regard to circulation in boilers, he not only did not believe in its value, but he thought it was one of the great elements of danger. It should be given up altogether, and the water converted into steam at one effort. Making two moves was only a confession that a bad boiler had been produced, so that after the water had been sent through the whole circuit it was unable to give off its steam, and had to be sent round again. The cold water should be lifted from the bottom of the boiler, and gradually warmed, so that when it reached the top it could take the shape of steam. The vertical tubulous boiler, well proportioned and contrived, would do everything that was wanted. Taking a single vertical tube (he did not care if it was sloped a little), if it were properly proportioned in surface and volume, and placed judiciously, so that the right quantity of heat came into it to convert the water into steam by the time it reached the top, that would be the best, simplest, strongest, and most durable boiler that could be made. He recommended the tubulous high-pressure boiler as the boiler of the future. He had no crotchets of his own, although perhaps he was the oldest boiler-maker present. Younger men were now doing the work, and the great value of such a Paper as that under discussion was that it would give a right direction to their efforts. No doubt there were dangers to be avoided. The danger of scaling could be overcome in many ways, into the details of which he could not enter. There was a great difficulty in having a proper furnace for a tubulous boiler. How it was to be overcome he need hardly say, but an envelope made of bricks or similar material was out of the question. With such additions a simple boiler would be converted into a complex one, and a safe and durable boiler into an unsafe and short-lived one. A great blunder was often committed in putting the coldest part of the heating surface where the greatest heat was wanted, and the hottest part where the least heat was wanted — a wasteful and injurious arrangement. Yet many persons thought they were making a good boiler and furnace when they put the cold water, just as it was injected, at the hottest part of the fire. A good boiler should have the coldest part where the water was coldest, and the hottest part where the water had arrived at the final stage and was ready to flash into steam. He wished to direct attention to another mode of making a thin metal boiler fit to receive high pressure. He referred to the stay system—three sets of stays at right angles with one another—first introduced by himself in 1827. He took a cubical furnace, and put parallel stays very close to each other in one dimension, another set close to each other in the second dimension, and a third set in the third dimension. He made boilers for marine and land purposes, of various sizes, of a thickness of only $\frac{1}{8}$th inch, and they worked with a pressure of ten atmospheres. The plan was afterwards adopted by Mr. Stephenson in the fire-box of his locomotive engine. For a long time a great firm in Liverpool did not believe in the square fire-box, and for twenty years they sent out cylindrical ones. By adopting the cubical boiler he had described, a square furnace could be used to hold the fire, all surrounded by water, and parallel tubes in any direction, very much like the modern marine boiler, except that the latter had not been carried out to the extent he had mentioned. He did not recommend this boiler as better than the tubulous boiler, although, as an invention of his own, he had a great affection for it. He regarded Mr. Perkins' tubulous boiler as a grand discovery. It required however, for its successful working, wise people to make it, and well-trained engineers and stokers to work it.

Mr. Spencer said he had omitted to mention, with regard to the weight of tubulous boilers, that in the case of the four boilers equal to 800 indicated HP., to which he had referred, there was a saving in boilers and water of 40 tons. There was no brickwork of any kind, and the boilers could be handled with impunity.

Mr. McFarlane Gray said that the Author had very clearly explained the present position of the question of boiler construction for higher pressures. His examples very well illustrated the principal directions in which boiler schemers were moving; and if there were little to commend in the plans described, the Author was not responsible for these plans. He had produced a Paper which contained ample material for discussion. Evidently there had been a great deal of scheming and altering, and but little, if any, progress. It appeared to him that the mere alteration of form or arrangement of heating surface, unless to serve some purpose of convenience or cheapness of construction, was of no importance; it did not matter much how the heating surface went so long as there was enough of it. He did not agree with those who condemned the present form of cylindrical marine boilers for the highest pressures now in use. He thought the facility they afforded for thorough internal inspection was apt to be undervalued. He considered that with such facilities there could be no excuse for such a boiler bursting. He had for many years been asserting that there was practically nothing to be gained by higher pressures unless under exceptional circumstances. He considered 100 lbs. pressure as rather above than under the highest economical pressure. A table given by the Author as a quotation from him (Mr. Gray) had been constructed on the occasion of the publication of a Paper by Mr. Alfred Holt in 1873. The following statement occurred in that Paper: "It may safely be asserted that if suitable boilers could be constructed for still higher pressures, and an engine with durable parts devised, the present consumption might be halved to-morrow."[1] It was to meet this remark that the table of twos was put forward. The principle of the table was Mariotte's law. The modifications due to the less percentage of back pressure loss at higher pressures, and the increase of initial energy, and the decrease of pressure by volume during expansion according to thermodynamic expansion, were set off as cancelling each other. These items therefore had not been neglected; they were eliminated. The table by the Author, in which back pressure was fully calculated, but the thermodynamic reduction neglected, was fairly corroborative of the simpler table of twos. It was a significant criticism of the value of higher pressure economies, that in his recent Paper before the Institution, Mr. Holt gave the same figures for the progress in economy which he had given in his pamphlet of 1873; but he now considered that the greatest possible advance to be ever attained with the steam engine at any pressure could not exceed 20 per cent. upon the present efficiency. This statement was a revise of Mr. Holt's forecast, after five years' further experience, and those who were now so sanguine in their expectations from higher pressures, ought to weigh well together these two statements. The starting data of the table of twos were from Mr. Holt's Paper, and the arrangement alone was his own. In reference to the oil and water boiler described in the Paper, a plan was now being introduced for the prevention of priming in boilers by the use of petroleum with the water. He thought these circumstances might be taken as suggestive of a boiler to work with water and oil more successfully than the compound oil and water boiler of Mr. Barron. As water and petroleum

[1] *Vide* Remarks on the construction and strength of the cylindrical parts of steam boilers, by Alfred Holt, p. 4. 8vo. Liverpool, 1873.

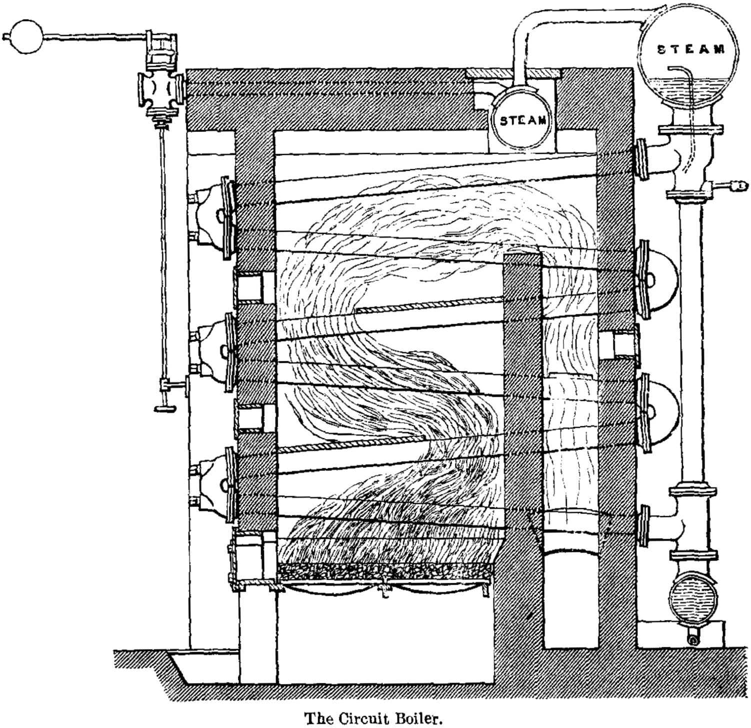
were not mutually soluble, he should expect that the pressure of the mixed vapours of water and petroleum would be the sum of the pressures of the vapours of each at the temperature of the liquids. The difference between the temperature of the gases in the flues and that of the liquid in the boiler would therefore be greater than in a steam boiler at the same pressure, and the efficiency of the heating surface would be thereby increased. In the plan of Mr. Barron the opposite of this would occur, and more than twice the present heating surface would be requisite. Then, in respect to priming, it was not known how petroleum operated to prevent priming; but in the case now considered, where the excess of pressure due to petroleum was to be considerable, it was easy to see how it might act with that result. Priming was an inconvenient excess of steam globules in the liquid. If the two liquids did not mix, the vapour globules formed in the liquid, if any, would each contain the vapour of only one of the liquids. But the vapour pressure in a globule must be at least equal to the pressure of the liquid about it; and it also could at most be only the pressure due to the temperature of the liquid; that was, it could not as vapour exceed the pressure due to one of the liquids, while the pressure to which it was subjected was the sum of the two pressures. It followed that no vapour globule could be formed in the liquid, and therefore there could be no priming. The vapour would be in that case formed at the liquid-steam surface, and the solid matter left would be suspended in the liquid. When the conditions were such as permitted the formation of vapour globules in the liquid, these would be mostly formed at the metal-liquid surfaces, and the solid matter would be left as scale on the metal. These remarks were merely the communication of the suggestion which occurred to him while reading the Paper, and if it were followed out to the complete explanation of the action of petroleum in boilers, or to the better understanding of priming, the expression of this thought here might, in his opinion, not be quite valueless. In the use of petroleum in boilers with surface condensers, it would probably be found that the oil would, at each evaporation, become more and more volatile, until its molecules were as light as they could be. This successive evaporation was called in America "cracking" the oil. If this were the case a light ought not to be brought in contact with the gas that would be found in the hotwell. With regard to air hanging about the surface of the tubes he thought there must be some mistake, considering the enormous velocity with which the products of combustion passed out of the chimney. With reference to the trouble occasioned by cylindrical boilers leaking at the bottom, that had been considerably amended by cementing with a cement mixed with pitch, which made it adhesive and elastic.

Mr. CRAMPTON said he was sorry to find the question of fuel consumed by the engine mixed up with the boiler question. The two things should be kept perfectly distinct. One made the steam, and the other used it. Then the Paper gave no amount of surface for the quantity of water evaporated in a given time, or the temperature of the gases escaping into the chimney—most essential points in the investigation of the boiler question. His opinion was that it mattered little what kind of surface was employed; almost any kind or condition of surface sufficed if the flues were arranged accordingly. It had been stated that there was no circulation in the Perkins boiler. He could not conceive that steam could escape from a particular surface, and that water could gain access to that surface, without circulation. The extraordinary results produced by the Perkins boiler had astonished him greatly. He could not see how the circulation took place, but that it did take place was certain. No doubt it was a good thing to get a boiler to stand a very high pressure, even if not used; but it was doubtful whether high-pressure boilers were of any commercial value up to a certain point. Occasionally there were reports of great results by the indicator diagram—200 or 300 lbs. pressure of steam per square inch and $1\frac{1}{2}$ lb. of water consumed per indicated HP. He thought these reports were fallacious. It was necessary to know what was the actual power developed by a given weight of steam, and the quantity of water evaporated by a given surface in the boiler before coming to a decision as to what was best. The diagram gave the quantity of power absorbed in the engine, but it did not give the work done. He had made some experiments upon the question about twelve years ago, being always opposed to excessively high pressures, and not believing in the value of very great expansions. The curve showed there was not really the value that might be expected, particularly at very high expansions. Taking 40 lbs. steam-pressure the value was 21; at 80 lbs., 25; showing a theoretical gain of 20 per cent. From 40 lbs. to 300 lbs. the gain was 100 per cent.; but then the problem was how to deal with 300 lbs. pressure of steam as against 40 lbs.; and all the parts would have to be strong in proportion. In the experiment to which he alluded, and which had been continuously at work for twelve years, he had the opportunity of doing as he pleased. There were water tanks which could be filled with water, and he proportioned the engine (20-inch cylinder and 20-inch stroke) up to 80 lbs. pressure of steam, in order that he might reduce from 80 lbs. down to whatever might be required to do the work. He tried experiments at 80 lbs., 60 lbs., 40 lbs., and 30 lbs., varying the expansion from 5 to 12 times. The result in all cases showed, by the theoretical diagrams, as nearly as possible the theoretical gain to which he had referred; but when he looked into the tank, the corresponding quantity of water was not there. That led him to inquire how it was. He ought to have lifted 20 per cent. more water with the same fuel; but practically he did not get any more. Where were the 20 per cent. lost? He believed that the additional friction by extra condensation and various other causes consequent upon high pressure would absorb the 20 per cent. and that it was better to use 40 lbs. instead of 80 lbs. pressure of steam, particularly in small engines. In very large engines where the losses would be relatively less some little advantage might be obtained, but not much. He had not used a drop of oil in the engine. The tops and bottoms of the cylinders and the sides were well jacketed, and the whole apparatus was well clothed. There was sufficient condensation of the steam (only super-heating from the temperature of the boiler in the jackets) to give enough water in the cylinders to lubricate them. There was surface condensation also; he had therefore no oil in the boiler. He thought it a pity that some established facts were not obtained to show what was practically the ultimate useful pressure attainable. His impression was that the high pressures sought for would not be found commercially advantageous.

Mr. R. W. Perkins remarked, with reference to the development of steam in proportion to the space occupied by the boiler and the weight, that a great deal depended upon the intensity of heat and rapidity of combustion, but a mechanical difficulty had hitherto presented itself. He had found on one or two occasions that in thus intensifying the heat to obtain the highest development of steam, the grate bars melted in three or four hours. To avoid this he adopted the plan of a bar in connection with a steam jet or other suitable blower, which system he had patented, and he thus obtained steam in the proportion of two boilers to three, and the bars were cool at the end of the operation. It would allow of anthracite coal being used, which, from the slowness of its combustion, had hitherto been found quite inappreciable as a steam generating fuel except in cases where this was compensated for by a very large boiler capacity, and therefore increased area of heating surface. Naval officers would be delighted to use anthracite coal, because it would enable a ship at sea to escape the observation of the enemy. The bars were hollow, and perforated so that the blast went through them, and then into the fire through the holes in the side. The intensity of the heat would be in proportion to the cooling of the bars, because both were determined by the rapidity of the cool air going through the holes.

Mr. OLRICK said he agreed with the Author that the great point to be considered in the construction of boilers was to make sure of a good circulation, so as to convey the more heated water away and allow the cooler portion to come under the influence of the heat as soon as possible. The failures of tubulous boilers had all arisen from the want of circulation, and from the boilers not being accessible to examination and removal of incrustation. He did not think that a proper circulation could be said to exist in a boiler where the upward current was not absolutely separated from the downward current. The upward current was a constant natural self-acting rising current, of a mixture of steam bubbles and hot water, contiguous to the heating surface, and which helped to wash off the steam bubbles clinging to the heating surface and to carry them through the water level to the steam space above; whereas the downward current consisted of water only, and as it was absolutely separated from the upward current, it was impossible that it could obstruct its course. The result was that in boilers with good circulation there was a great economy of fuel. By putting a Galloway tube into a Cornish boiler there was a separation of the two currents, and as the steam and water in the Galloway tube was considerably lighter than the water outside, between the shell of the boiler and the flue, a perfectly natural self-acting current would take place. The reason why the Davey Paxman boiler was a good evaporator was that there was a separation of the two currents. In the Field tube it was the same. Taking away the internal circulation, what would be found? The same state of affairs as in a railway station where there was only one staircase, and one set of people trying to leave the station and another set trying to catch a train at the same moment. The result would be an absolute block of passengers. Mr. John Fowler, Past President, had exercised a wise discretion in making at all his railway stations two staircases, thus compelling a separation between the two currents of passengers, one representing the up-draught, the other the down-draught. The best of the boilers described by the Author was the Watt, because there was a separation of the up and down currents; still a certain amount of the down-draught tube, acting as heating surface, and some ebullition took place that ought not to occur, because the down-draught tube ought not to be used as heating surface. It had also a number of flat surfaces that ought to be avoided in the case of very high pressures. The Root boiler consisted of a great number of small boilers, each tube being a separate boiler, and there was no circulation in the tubes in the sense he had described. The Belleville boiler had been applied to a number of steamers in the French Navy, but it had suffered from the same defect of circulation. The Perkins boiler, which was the same as the "Montana," had been successful while the other had not. The "Montana" dealt with a steam pressure of 60 or 70 lbs. per square inch, and at that pressure the number of cubic feet of steam evaporated from 1 cubic foot of water was 300; whereas the Perkins boiler dealt with pressures of 500 lbs. per square inch, and at that pressure the number of cubic feet of steam evaporated from 1 cubic foot of water was only 60; so that there was three times the area for the upward current to pass through, and five times less cubic contents to pass through the vertical tubes. The Author had expressed a doubt whether a down-draught, independent of the up-draught, could be made. Mr. Olrick had placed on the wall a representation of what he had called the "Circuit" boiler, Fig. 2. It had been designed to remedy the shortcomings of the Belleville boiler, which had parallel tubes of the same diameter throughout; and the steam had to find its way to the steam dome in an irregular manner, as there were no means for separating the upward and downward currents. In the Circuit boiler, the tubes were all slanting to assist the ascent of the water and the steam. It would be observed that, as the tubes got higher and higher, they were larger and larger in diameter, to allow for the space that the steam bubbles mixed with water would occupy. There was a down-draught tube which enabled the water to pass downwards, and the steam went into a dome at the top of the boiler, with a super-heater or dryer. Every joint in the boiler was outside the fire. The whole boiler was made of wrought iron. To examine the boiler for dirt it was only necessary to take out a small plug in the first instance, and if required the joints of the bend could then be broken. The feed-water was put in at the top of the down-draught tube, so as to enable the cold water that came in to be heated to a sufficient temperature to precipitate any impurities that might be in the water, and leave them in the receiver at the bottom of the boiler, from whence they were blown off by the usual blow-off cock, *thus preventing the impurities* from being carried in over the heating surface. The back or down-draught tube was not heating surface, therefore the water was cooler than in the other parts of the boiler. If the boiler were applied to a man-of-war, and a shot were fired into the engine-room, the explosion would be far less destructive than in

Fig. 2.



The Circuit Boiler.

one of the existing boilers 10 feet in diameter. Again, if the boiler were entirely destroyed, it would be only necessary to send to the store-keeper of the ships, and in less than a week a new boiler could be built up without breaking a single plank. Considering how much depended upon the fleet for defence and attack, he thought that the Government would be spending money well in trying the Watt boiler, the Perkins boiler, and the Circuit boiler.

Mr. Flannery said Mr. Cowper had charged him with omissions in the Paper, because he had not described certain boilers used twenty years ago; and Mr. Longridge had also complained of the omission of details; but what length did those gentlemen expect the Paper to run to? Mr. Cowper had further complained of the title, and had asked what he meant by "very high pressures"? The title had been suggested by the Council, and he had simply adopted the suggestion. He had not, as Mr. Cowper seemed to imply, advocated all the boilers he had described as being a solution of the boiler difficulty, or as the proper types of boiler to be used, for he had seriously condemned many of them. The curve in Fig. 1 (page 126) involved a slight error, being calculated by hyperbolic logarithms, and not being strictly an adiabatic curve. This had been stated in the Paper. With reference to the contention of Mr. Longridge, that locomotive boilers possessed all the advantages of boilers such as those described in the Paper, and not many of their disadvantages, he would dispose of it by saying that a locomotive boiler had necessarily a confined steam space. In the case of large cylinders with a slow movement, there was a tendency to priming. In locomotives there were small cylinders working at high speed, and steam was withdrawn from the steam space almost continuously. Mr. Longridge had asked for an explanation of the statement with reference to contact with heated gas when passing along the surface of the flue. He had no other authority to produce than that of Mr. Wye Williams, who had made the statement and supported it by experiment. It seemed reasonable to suppose that if the heated gases were passing along the surface of the plate at a high speed they would not convey their heat to it so directly as if they impinged upon it at right angles. Mr. Longridge also inquired why he had assumed that high pressure promoted circulation? Circulation was the mutual changing places of water and steam. With high-pressure steam there was a given weight, say 1 lb. of steam occupying space inversely as its pressure; and it was evident if the space occupied was smaller, the space through which it must travel, in order to change places with water, was also smaller. It was, therefore, easier to circulate water and steam in a boiler of high pressure than in one of lower pressure. It would be found, from a table of temperatures, that there was a very slight difference in the sensible temperature of steam at high pressure and of steam at low pressure. There might be many times the pressure of steam with very little increase in the sensible temperature. With reference to the alleged danger and weight of firebrick, the calculation referred to in the Paper as to the Watt boiler, included a large amount of firebrick, which was necessarily a considerable item in the total weight of that boiler. Mr. Perkins had succeeded in doing away with this objectionable feature, because he had introduced, to contain the flame, a double sheet of iron plate with charcoal between. This prevented the radiation of heat, and it was much lighter than firebrick. Mr. Crampton had charged him with not dealing with the subject completely, because he had mixed up the questions of the engine and the boiler, and had spoken of the consumption of coal in the engine and boiler, and not of the evaporation of water. But Mr. Bramwell had shown again and again how important it was to make sure not to mistake evaporation for priming—not to assume that the water primed into the engine was evaporated. Unfortunately, there were few experiments with water-tube boilers on any large and reliable scale showing their evaporative efficiency; and he was unable to bring them forward. All that he could do was to give the results shown in the "Propontis" and other examples where tests had been made of the consumption of coal. With reference to the remarks of Mr. R. W. Perkins he might mention that he had spent a fortnight or three weeks in conducting experiments made on that gentleman's system of firebars. His object seemed to be to reduce the space and weight necessary for a given development of steam. Those experiments gave the very highest encouragement to believe that two boilers would suffice where three were now required, because of the more active combustion, due to the blast passing through and afterwards out of the bars. He was glad to find that an engineer of so much experience as Mr. Olrick agreed with the views expressed in the Paper. It appeared that there were two sorts of boiler; one was a water-tube boiler which might be successful, in which there was ordinary circulation, or, as Mr. Olrick had put it, an upward and downward current perfectly separate; in the other, which might also be successful, as suggested by Mr. Scott Russell, the water rose without change of motion from the lowest part of the boiler to the highest, and then evaporated. In that case there was no circulation in the ordinary sense of the word.

Mr. R. V. J. Knight remarked, through the Secretary, that higher pressures and greater expansion would entail increased condensation in the cylinders, which condensation would, he feared, take away at least one-half of the gain promised by theory, and would, in fact, practically limit the extent to which expansion might be carried with economy. As the present type of high-pressure marine boiler would continue in use for the next few years, it might be useful to see how far it could carry higher pressures with safety. He would confine his remarks to the strength of the cylindrical shell, the part to which the Author more particularly alluded. Fortunately, reliable steel plates could now be obtained, which would be of great assistance, unless boiler constructors were too much fettered with official restrictions. Before stating the inferences he had drawn from experiments made at his request, he would record the results obtained, as they might induce other engineers to publish some of the valuable experiments which no doubt they had undertaken. To ascertain the practical damage done by punching holes in steel plates for boilers, and the effect produced by connecting, the following preliminary experiments were made. From a plate of Landore steel $\frac{5}{8}$ inch thick, three plates, 6 inches wide and 16 inches long, were cut. In the first and second plates, three 1-inch holes were punched, at 3 inches pitch, arranged zig-zag. The first plate was not annealed after it had been punched, but three red-hot rivets were closed in the holes in the usual way, and it was then planed down to 3 inches wide, so that two of the rivets were cut through their centres, and one rivet was left in the centre of the plate untouched. The second plate was made red hot after it had been punched, and was then treated in the same way as the first plate. In each plate were therefore two sections of equal area, but both plates broke through the centre rivet-hole. The third plate was planed only 2 inches wide, having the same section as the first and second plate, and was left in other respects in the state in which it was received from the maker. The first plate broke under $31\frac{7}{8}$ tons pressure, the second under $32\frac{5}{8}$ tons, and the third under $33\frac{1}{8}$ tons, or under $25\frac{1}{2}$ tons, 26 tons, and $26\frac{1}{2}$ tons per square inch of net area. The loss was 2 per cent. for the plate annealed after punching, and 4 per cent. for the plate not annealed. As in practice all punched holes are closed with red-hot rivets, it was considered only fair to give them any benefit which might be derived from the rivets by supporting or annealing. Instead of continuing this class of experiments, it was thought more useful to test double-riveted lap joints of steel against the same kind of joint of iron. Two joints of best Staffordshire iron, and three joints of Landore steel, were prepared, all alike, except in thickness, which was proportioned inversely to the expected ultimate tensile strengths of iron and steel. All the joints were 9 inches wide, all the holes were punched, and each joint was connected by six 1-inch iron rivets. The iron plates were $\frac{7}{8}$ inch thick, and the steel plates $\frac{5}{8}$ inch thick. The iron joints were torn through the rivet-holes by $71\frac{1}{10}$ tons, and $73\frac{2}{10}$ tons pressure on a mean tensile strength of $13\frac{8}{10}$ tons per square inch of net area of joint. The ultimate tensile strength of the iron plates was $21\frac{1}{2}$ tons per square inch. The first steel joint was not annealed after punching; the second steel joint was warmed to a blue heat after punching; the third steel joint was made red hot after punching. In each case the iron rivets were sheared by $93\frac{1}{2}$ tons, $91\frac{2}{10}$ tons, and 92 tons pressure respectively, or $18\frac{1}{2}$ tons per square inch of rivet area. The ultimate strength of the plates was 27 tons per square inch. The plates sustained, without fracture, a tensile strain of $24\frac{6}{10}$ tons per square inch of net area of joint, or about 10 per cent. less than the ultimate tensile strength, although two of the joints had not been annealed after punching. The $\frac{5}{8}$-inch steel joints were 27 per cent. stronger than the $\frac{7}{8}$-inch iron joints, but per square inch of net area they were 78 per cent. stronger; therefore for lap-jointed boiler shells it would have a great advantage over iron, but for but-jointed boiler shells the advantage would be only that due to the relative strengths of iron and steel, say 30 per cent. The die used in all cases was one-sixth of the thickness of the plate larger than the punch, which proportion had been found to work well both for iron and steel of mild quality. Applying the term "Theoretical strength of the joint" to the product of the net area and ultimate tensile strength of the material, then the actual strength of the joints (including those published in Vol. li. of the Minutes of Proceedings, page 131), expressed in percentages of the theoretical strength, would be as follows:—

	Per Cent.
For the 1-inch lap joints	56
„ „ $\frac{7}{8}$-inch lap joints	64
„ „ 1-inch but joints	90
„ „ $\frac{5}{8}$-inch steel lap joints . . .	90

In all his experiments on double-riveted lap joints with punched holes, he found this percentage increased as the thickness of the plates decreased, being about 85 per cent. for iron plates $\frac{3}{8}$ inch thick. Although these iron joints varied in strength from 56 up to 90 per cent., yet he knew of no published rules which took these great differences into account. The Board of Trade rules only allowed 5 per cent. increase of strength for the but over the lap. Supposing three boilers to be of the same diameter, the first made with a double-riveted lap-jointed shell 1 inch thick, certified by the Board of Trade for 70 lbs. pressure, then if the second boiler was made with a double-riveted but-jointed shell 1 inch thick, it would be equally safe for 112 lbs. pressure; and if the third boiler was made with a double-riveted but-jointed shell, 1 inch thick of steel, it would be equally safe for 146 lbs. pressure. The working pressure allowed by the Board of Trade would be about 75 lbs. for the second, and about 95 lbs. for the third boiler. Although 146 lbs. pressure could not be called a "very high pressure," yet it would be welcomed by all advocates of higher pressures. His own impression was, that although higher pressures would lessen the consumption of fuel, yet that the additional economy effected in the working expenses would be very small.

Mr. E. B. Marten observed, through the Secretary, that the Author was evidently unaware of a report on some most careful experiments on the evaporative duty of five samples of tubulous boilers conducted by the American Institute at New York, of which the following was an abstract:—

"Some of the most careful experiments on record, where the evaporative duty was ascertained by condensing the steam and measuring the actual heat conveyed, gives the duty of the Root boiler as 8·76 lbs. of water per lb. of coal.

"The same experiments showed the duty of other tube boilers as nearly the same, viz.:—

	lbs.
The Allen	8·76
The Phleger	8·70

and compared them with two others with external shells—

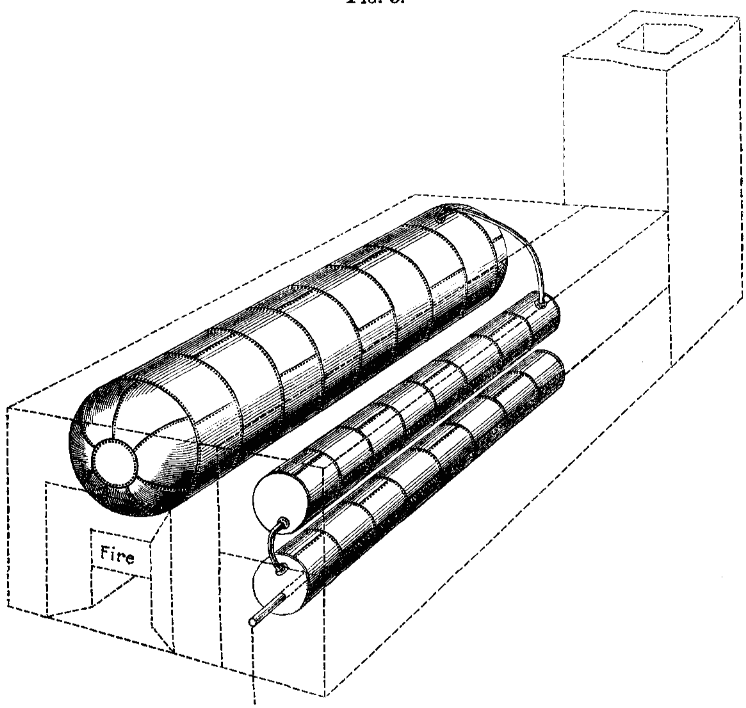
	lbs.
The Lowe	8·55
The Blanchard	9·41."

One of the advantages incident to the system of periodical inspection of boilers which he had conducted for many years, was, that the same set of observers noted during long periods the behaviour of many thousands of boilers of every variety of type, so that a larger amount of useful information was gained than would be possible in a private practice. From his own observation and experiment he could confirm the Author's statement that nearly all boilers, placed in proper circumstances, would give about the same evaporative duty; but in practice, economy of capital, space, and time, was often of more importance than mere economy of fuel. He had watched the working of the Howard, the Root, and the Perkins boilers, like those mentioned by the Author; and also other tubulous or small water-space boilers, such as the Benson and the Harrison. Some of them had shown that tubulous boilers did not always mean freedom from explosion and loss of life; but further attention to details of construction would reduce that danger to a minimum. The chief cause of difficulty was the need of pure water, and of ready control over the fire, to enable it to be reduced as suddenly as the demand for steam. The result was that unless the very high pressure for which tubulous boilers were intended was made use of, many of the old forms of boilers were better. The Perkins boiler alone fulfilled the expectations formed of it, owing to the unusual care bestowed on its mechanical details, and to the adoption of the important principle of working the same water continuously, making the water as it were a reciprocating part of the engine. By means of small glass eye-pieces in boilers he had made many observations on circulation, and had come to the conclusion that a steady advance of the water from the coldest to the hottest place was the better principle, the water going one way and the heat the other. Circulation, or the return of the hot water to the cooler part, involved loss, because the whole boiler must thus be kept up nearly to the heat of the steam, and the gases must escape at a high temperature. A simple form of boiler was shown in Fig. 3. It was very effective and economical because circulation was impossible, although there might be a good deal of useful agitation just over the fire. It consisted of a large plain cylinder under which was the fire. There were two side tubes of the same length as the larger one, but of half the diameter; and the heat passed completely round the upper, and then returned around the lower tube. The only connections were the single copper pipes, and these not being rigid each cylinder was free to expand. The water entered where the heat was least, at the back of the lower side tube which was quite full, and then rose into the upper side tube, also full, and fell into the large cylinder where the last increment of heat was added to evaporate it. If the water contained scale-making impurity it was left in the first tube, where, the heat not being sufficient to harden it into scale, it was blown out as mud. Evidence of the correctness of this principle had been shown in the fact that since cross tubes

M 2

had been added to the old slow-working Cornish and Lancashire boilers, more work had been done in a given time, but at a loss of evaporative duty from the fuel. This had only been partially prevented by the economiser, to bring the heat back from the flues beyond the boiler, which acted the same part as the side tubes in the boiler described above, with more danger of being choked with

FIG. 3.



Boiler without circulation, the feed advancing steadily in the opposite direction to the heat, so that the whole available heat is brought back from the flue. Feed-pipe carried to the back. Boiler also capable of very high pressure if two smaller cylinders are substituted for the large evaporating one.

scale. It was estimated that about 75 per cent. of the stationary work of the kingdom was done by the Lancashire or Cornish boilers of various types, and it was natural that the general belief should be that such ponderous and complicated structures were alone suitable for the purpose. It was to be hoped that investigation would be continued; and that a more handy evaporator would be the result, capable of varying the supply of steam as needed, so as to do away with the present necessity of a large but dangerous store of force in the shape of highly-heated water.

Mr. D. Phillips remarked, through the Secretary, that he did not think many engineers of practical experience held the same views as the Author. As to the gain to be effected by much higher pressures of steam than those commonly in use, what seemed to him to be wanted was knowledge acquired from practical illustrations, and on a much larger scale than hitherto attempted, and not assumptions derived from theory, or deduced from mathematical problems. In estimating the gain which it was believed by many would be effected by pressures five or six times greater than that in ordinary use, on a large scale, and for long sea voyages, numerous points might be considered. Among these were: first, the original cost of the machinery; secondly, complexity of the machinery, and the wear and tear of the principal working parts, especially if it should be attempted to derive the full benefit of expansion with too few cylinders; and, lastly, the much greater care which would have to be exercised by, and the responsibility which would necessarily devolve on, those in charge of the engine-room. Difficulties, no doubt, presented themselves when the leap was made to construct and work marine engines with double the pressures carried sixteen or seventeen years ago; but those difficulties had, happily, been overcome, leading to a great saving, especially in fuel. How far this might be successfully carried out in practice was doubtful. Of the various plans of steam generators to withstand high pressures exhibited by the Author, there was but one capable of carrying a higher pressure than 50 lbs. per square inch with safety, and that only so long as the conditions of working were safe. For 500 lbs. pressure and more, Perkins' water-tube boiler was the only example he knew of capable of being worked with safety; and, as one of the many examples brought to the notice of the late Boiler Committee, he could speak of it as being fully up to the mark. No doubt the larger the diameter of the tubes in a generator of this type the greater must be the cubical contents; and that being so, the greater would be the probable mischief in case of an explosion. Again, the smaller the diameter of the tubes the less accessible they must be for examination *in sitû*, which might be objected to in such a boiler as the Perkins; but, on the other hand, if the boilers could be worked with water free from solid matter, as pointed out in the report of the Boiler Committee, and which was effected by the Perkins plan on a small scale, no danger need be apprehended from incrustation and consequent "burning" of the iron. Should, however, sea water, though not on account of the salt or grease from the engine, reach such a boiler to a serious extent, no doubt it would in a short time, as in the "Propontis" boilers, prove fatal to it. That danger was to be apprehended at sea, especially with large engines and boilers running on long voyages. However perfect the machinery, hitches sometimes occurred, and the tallow-kettle, or oil-can, would be resorted to. Again, the best condensers might become leaky, and sea water find its way freely into the boilers. The area of the vertical connecting tubes of the Perkins boiler was ample, as pointed out by the Author, "for the free escape of the steam, and for the prevention of injury from overheating of the tubes in contact with the flame," in the rather small boilers at work; but he should doubt their efficiency, if boilers of this type were to be made on a large scale, with a proportion of heating surface corresponding to their size, especially if made much higher. In this respect, and as a steam generator, the boiler might be easily modified, and, he thought, with great advantage.

On the vexed question of different waters, and their effects on the iron boilers, on many important points chemists were not only at variance with each other in theory, but at variance when the results of their laboratory investigations were compared with those obtained by actual practice. The practical engineer had been misled, in many instances, by reports founded on such results; but more so, perhaps, by some of the theories well known to the chemical world, and only superficially by engineers. Now it was generally accepted as a fact, that distilled water *per se* was, under almost all conditions, much more injurious to iron than rain or ordinary fresh water, especially if used "over and over again;" and that the denser or more salt the water became from evaporation, the more destructive it was to iron. On these points some interesting experiments had been carried out by the late Boiler Committee, and the results, as yet unpublished, had proved the fallacy of many existing theories. These experiments showed that, in the comparative absence of air, there was scarcely any oxidation of the surfaces, after a period of two years, with either of the following waters, viz., salt water $\frac{2}{32}$, and sea water $\frac{1}{32}$ in density, well water, rain water, or water distilled from sea water. In similar waters, with air present, but without changing the waters, except a little in one or two instances on account of leakages, the results were very different, both in the nature and severity of the corrosion. The tubes which had fresh water in them on the whole suffered more seriously than those which contained salt water, the corrosion in the former being of a local character; deep pits being confined principally to the neighbourhood of the water level, and extending but diminishing in depth and size to the bottom of the tubes. The corrosion in those tubes which contained salt water was confined to the steam space, principally near the level of the water, and gradually decreasing towards the top of the tubes; but it was more general, though of less depth, than when fresh water was employed. With regard to the action of water distilled from sea water, under the same conditions of working, there was scarcely any difference between either the nature or the extent of the corrosion, compared with the action of fresh water, except that it was very slightly more marked at the lower part of the steam span in the boiler containing distilled water. With a short series of plates, 4 inches long and broad, and $\frac{3}{8}$ inch thick, having bright surfaces and suspended in open vessels at a temperature of about 210° or 212°; the first was in a vessel containing soft fresh water; the second in a similar vessel with water distilled from the same water as the first; the third was in a vessel with an admixture of both fresh and distilled water; and the fourth and last, in a boiler working at a pressure of about 50 lbs. per square inch, fed with water from the latter vessel. The following results were obtained after a trial of thirteen months' duration :—

	Grains.		Grains per Square foot of Surface.
First plate in water supplied direct from the main lost	264·0	or	1006·5
Second „ „ distilled from the same water „	313·5	„	1462·0
Third „ in an admixture of both waters . . . „	405·0	„	1544·0
Fourth „ in boiler . . . . „	20·0	„	76·2

The difference in the nature of the corrosion was remarkable; the first sample was corroded in the form of pitting (somewhat like shot marks); the second was corroded uniformly, nearly smooth all over, with the edges quite sharp; while the third was corroded unevenly, but more irregularly in form than the first; and the fourth specimen was scarcely affected. In this experiment an incident occurred which no doubt had a great deal to do with the result. The grease (mineral oil), resulting from the use of a surface condenser for six months and a half out of eight, got into the second vessel in rather large quantities, and still more so into the third, and protected the plates in a most extraordinary manner.

Thus, during the first period of the experiment, while the first plate lost 180 grains, the second only lost 13 grains, the third 11 grains, and the fourth 7 grains. From this it would appear that the first and fourth plates could hardly have been subjected to the influence of the oil during the six and a half months that the condenser was at work, although some of the oil had reached the boiler. When this was found out, the vessels and boiler were thoroughly cleansed of oil, and the communication with the surface condenser was closed for the rest of the time. He would next refer to one of a series of experiments carried out in glass bottles containing water at atmospheric temperature, with round pieces of polished iron of the same size, connected by a small brass rod to a brass disc, the other conditions being the same in each case, and the time twelve months.

	Grains.		Grains per Square foot of Surface.
First sample in water of $\frac{10}{32}$ density, or nearly saturated, the loss was only	5·6	or	105·1
Second sample in water of $\frac{6}{32}$ density, or 6 times that of the sea, the loss was only	6·1	„	114·5
Third sample in water of $\frac{3}{32}$ density, or 3 times that of the sea, the loss was only	12·7	„	238·4
Fourth sample in water of $3\frac{1}{2}$ density (sea water), the loss was only	13·2	„	247·8
Fifth sample in water, as used at Whitehall, the loss was only	16·2	„	304·1
Sixth sample distilled from fresh water, the loss was only	12·0	„	225·2
Seventh sample distilled from sea water, the loss was only	12·4	„	232·0

In another series, where the area of the surface of the water was a little larger, and the quantity of water in the bottle one-third less, the following results were obtained:—

	Grains.		Grains per Square foot of Surface.
First sample in distilled water, *per se*, the loss was	34·4	or	535·8
Second „ „ „ from sea water „	23·2	„	359·9
Third „ in sea water „	24·0	„	372·5

In this case the difference was greatly in favour of sea water, the time being the same in the first and third cases (twenty and a half months); but in the second instance, only a little more than twelve months. The proportion of loss between the first and second cases therefore was as 39·6 in water distilled from sea water to 34·4 in the distilled water *per se*. In the first series the loss was less in the distilled than in the sea water, which was due to the absence of salts when brass was connected to the iron, although the corrosion showed no appearance of "galvanic action," as it was even and uniform all over. He would refer, next, to an experiment to ascertain the comparative effect of waters in marine boilers, one boiler being fed from an ordinary jet condenser, and the other from a surface condenser. The boilers were filled, and the waste was made up with sea water, and care was taken to reduce the waste as much as possible, the same water being worked "over and over again" in the latter case. In the former case the water was changed entirely fourteen times, and in the latter only twice during a period of nearly thirteen months. The time of work was about one-third of the whole; but with the boilers always under banked fires, except when the machinery was being overhauled. Although both iron and steel plates were used, he would only refer to the loss in the iron plates, which were bright, 10 inches long, 8 inches wide, and $\frac{7}{16}$ inch thick.

	Grains.		Grains per *Square foot* of Surface.
The average loss in the two plates suspended in the boiler fed from the jet-condenser was	1203·1	or	1018·2
In the two plates in the boiler fed from the surface-condenser the loss was only.	820·3	„	687·3

This indicated a saving of about 48 per cent. in favour of the surface condenser, and changing the water as little, and opening the boilers as seldom, as possible. To show still more clearly the effect of changing the water, he would mention two cases obtained from another series of experiments, with engines having surface condensers in both instances, and in vessels in H.M. Navy. In one case "blowing off" and changing the water in the boilers were carried out to a most extraordinary degree, and in the other as before. In this, as in the above experiment, he would only refer to the iron plates, which were two in number, 4 inches long and broad by $\frac{3}{8}$ inch thick in each case. In the former plate the average loss was 556 grains against 118·2 grains in the latter, whilst the time occupied in the latter case was a little more than three times that of the former. This showed that at this rate of deterioration the boilers under the latter conditions would last about fifteen times as long as those under the former, provided the plates were of the same thickness, &c. The pressure carried in the first case was 40 lbs., against 30 lbs. to the square inch in the second; but he did not think this would make any practical difference. The last subject to which he would refer, bearing on the deterioration of marine boilers, was the "fatty acid" theory—a theory which scarcely ever escaped discussion when the question of deterioration of boilers was brought forward. He would refer to two experiments on this point; the first was carried out in a tube of copper, and the second in one of iron, the condition of working being the same in each. Water of $\frac{2}{32}$ density, $\frac{1}{2}$ lb. of tallow, representing the lubricant, and air, were admitted weekly, under an average pressure of 38 lbs. to the square inch. Iron placed in a vessel under similar conditions only suffered to the extent of 65·3 per cent. more than the iron tubes, which were each 8 feet long by $2\frac{1}{8}$ inches in diameter internally, with the water occupying about two-thirds of their length. In another tube under the same condition, except that 2 oz. of copper filings were added, the general surface of the tube, especially at water level and upwards, was in far better condition than of those tubes which contained neither tallow nor copper filings. Moreover, the plug in the bottom of this tube was the least affected of any in a group of ten tubes. Now if copper, in a metallic form, placed in a vessel of this kind, had no effect, on either the tube or plug, during two years, what effect could it have on surfaces of a working boiler? Scarcely any. He thought from the few experiments alluded to, and from some concluded by the late Committee, and others in progress, that the causes of the corrosion in marine boilers would be found not to be due to working them with "too pure water," or water "worked over and over again;" nor to the copper carried over in metallic particles, or in a dissolved or oxydised state; nor to water distilled from sea water; nor to fatty acids; although some of them might contribute, slightly, under certain conditions of working, to destroy the iron of the boiler. He believed the deterioration to be principally, if not entirely, due to the free admission of air and carbonic acid, resulting from the constant change of the water by "blowing off," &c., and from air mechanically introduced by the air and feed pumps; and last, but not least, to the exposure, which boilers underwent, to atmospheric influences when idle and open. Although it was impossible to work engines without slight leakages, and the use of pumps, yet the waste resulting from the former should be made up, and the water from the condenser should be delivered into the boilers charged with as little air as possible. This was, he believed, the secret of the satisfactory condition, internally, of Perkins' boilers. Moreover, these boilers, from there being no necessity to clean them, except occasionally, could be kept free from air when idle, in fact under a vacuum; and on account of the limited area of the stop valves and other connections, the boilers were less liable than ordinary ones to become leaky, either from friction of the steam, or from wear and tear of the surfaces. Of this he could vouch, from having watched the operation of disconnecting a section of the factory boiler of Messrs. Perkins, after it had been idle about three weeks.

Mr. F. J. Rowan observed, through the Secretary, that he thought the Author was in accord with the majority of engineers in his remarks on the advantage to be derived from the use of steam of higher pressures than those now in general use in steam ships. To what the Author had said about the diminished value of the areas for very high pressures enclosed in the hyperbolic curve, he would add that some further arguments, derived from the increase of strengths necessary, and the difficulty of lubrication, &c., had been advanced by Professor Osborne Reynolds among others, to show that beyond about 200 lbs. per square inch, the ratio of advantage derivable was much diminished. He fully concurred, also, in the Author's remark with reference to a suitable construction of boilers, that the requirements of this high pressure led directly to reduced diameters, or more correctly to reduced areas for fracture, and thus to water-tube or tubulous boilers. Expedients for strengthening existing cylindrical boilers, such as that recently proposed by Dr. Siemens, while they reflected credit upon the skill of their inventors, were from their exceptional character more likely to involve serious risk than the more simple method referred to by the Author. The increase of strength derivable from reduction of water and steam spaces was of course the direct argument in favour of such reduction, and here he would observe that while the Author acknowledged this, he betrayed inconsistency in his approval of the design of the Watt boiler, of which an essential part was a rectangular box with large flat surfaces at each end of the tubes. He was aware that these flat surfaces were stayed to obtain the required strength; but this did not eliminate the defect in design to which he alluded.

The subdivision of boilers necessarily resulted in an increase of the surface exposed to the action of the hot gases from the furnaces, and it followed that a larger portion of the heat produced by combustion might thus be utilised. It was in connection with this part of the subject that the Author, in common with many others, had introduced the opinion that, in order to realise this economy, the heating surface must be disposed horizontally so as to present surfaces at right angles to the currents of the heated gases; and as the gases usually ascended directly to the funnel, the only conclusion to be drawn was that the boiler must consist of horizontal tubes. He ventured to combat this opinion on the ground that none of the requirements of the problem, when closely examined, demanded such conditions. All the reasoning to be met with on this subject as to the comparative value of various kinds of surface, and as to the behaviour of layers of gas, proceeded on the assumption that the gases were allowed to escape either by a gradually ascending current or by direct vertical movement. But the conditions were altered if the gases were compelled to take a downward course before being allowed to escape upwards to the funnel. This effectually disposed of "layers" of gas, because it compelled thorough intermixture and circulation of the gases, the colder portions being those which of necessity escaped first. This result was independent of all question of position of heating surface. In fact, considered merely as affected by the hot gases, all kinds of surface would have an equal value if exposed to a body of heated gases treated in this way. Evidently, too, by this method of working, a nearer approach was made to a position of having the power of maintaining the contact between the hot gases and the boiler surface for the maximum time necessary to abstract the heat. It had been carried out in practice in almost all the examples of Rowan and Horton's boilers made since their introduction in 1858, and had been an important element in their economy of fuel. With chimney or suction draught, however, it was impossible to possess to the full the power of maintaining contact between the gases and the surface, until the gases were cooled down to the lowest point, because a certain portion of heat must in such case be sacrificed to the necessity for the creation of draught, in order that combustion might be assisted. This defect might be removed by introducing forced combustion, or combustion under pressure, and the speed of travel of the gases might with proper appliances on this system be regulated at will.

He differed from the Author about the position and powers of boiler surfaces and the action of layers of gas, because Professor Clerk Maxwell's investigations of the theory of heat, and those of other workers in the same field, had shown that the transmission of heat from the gases to the water was regulated simply by the time of contact of the heating medium with the iron of the boiler, and by the proper circulation of the water by which one face of the metal was maintained at a lower temperature than the other.

The rate of flow of heat was steady and could be measured, as it was proportional to the area exposed to heat, to the time and to the difference of the temperatures of the two faces, and inversely proportional to the thickness of the metal. The circulation of the water in the boiler, in this view of the case, very properly assumed a position of great importance, and he was glad to find some remarks by the Author on this part of the subject with which he heartily concurred. Yet, in opposition to opinions which he had expressed in other pages, he maintained that a properly constructed water-tube boiler could not have urged against it that it presented difficulty to the obtaining of good circulation; but that, on the contrary, it offered conditions for the realisation of thorough circulation such as could not be obtained in boilers of the ordinary cylindrical form or of other designs. If only natural modes of action were observed and provided for, the escape of the steam and upward movement of the currents of heated water, inducing the regular supply, from below, of portions to be heated would proceed in perfect order, and all the more efficiently that small quantities were set in motion in the individual parts of the boiler. The mere rapidity of circulation involved no danger, provided there was circulation, and not merely the rapid formation of steam without a proper supply of water. In boilers composed of horizontal, or nearly horizontal, tubes, there was great danger of the existence of this latter state of affairs, and the more rapid the formation of steam in them, the greater would be the obstacle to the access of water to the heated surfaces. When, however, as in a boiler of vertical or nearly vertical tubes, the escape of the steam itself assisted the movement of the water, it was manifest that rapid movement was no defect. It was really a decided advantage where there was any danger of a deposit of solid substances from the water; and a very interesting proof of this and of the comparative value for circulation of vertical and horizontal water tubes was in the possession of Mr. Parker of Lloyd's. He had shown him some tubes cut out of the same boiler, where, in the same part, some were placed horizontally and some vertically; the horizontal ones were salted up, some solid and some nearly so, while the vertical ones had merely a thin coating of scale.

He was surprised at the difference between the Author's remark, that "the escape of steam will be facilitated by the disposition of the heating surface horizontally," and that where he urged as a defect in most water-tube boilers that "the steam must travel horizontally before it begins to ascend." He must also challenge the fairness of his summing up of the recent discussion on circulation, in which he took some part, for the Author had instituted a comparison between horizontal tubes and vertical tubes which had not a proper supply of water to their lower end, and had concluded in favour of inclined tubes, as if vertical tubes did not exist in other conditions. If inclined tubes were good, as the Author indicated, what was the value of vertical or nearly vertical tubes properly supplied with water as in the boilers which he advocated?

If fresh water only was used in generating steam, there need be little or no provision made for access to the interior surfaces for cleaning. This removed one objection to water-tube boilers; but in this case corrosion from the action of carbonic acid and oxygen introduced into the boiler with the condensed steam must be provided against. There was also, in boilers working in long-voyage steamers, the chance of the leakage of a small quantity of sea-water into them with the feed, and this would intensify the corrosive action. From these actions no boilers were safe, and those of Mr. Perkins were subject to the same risk as the rest, so that it was necessary to introduce some protection. The Boiler Committee had shown that zinc afforded some protective power. In addition to its use there seemed to be two methods of working, viz., that of adding chemicals to the water to decompose some of the salts and render it alkaline, as proposed by the Committee; and that of protecting the boiler surfaces by the formation on them of a thin insoluble scale from fresh water, as proposed by him in a Paper on "Boiler Corrosion." The Author had referred to the "Propontis," but in his Paper which he had quoted, from the Transactions of the Institution of Naval Architects, he dealt with this example of Rowan and Horton's boiler as if it had been the only one tried. This was not the case. In the discussion on Mr. Holt's Paper,[1] he alluded to the fact that in one shape or another these boilers had been worked from the year 1858. During that period the s.s. "Actif," of the French Navy, quoted by the Author, was one of the instances, she having been originally fitted with these boilers, and even after their removal retaining the three cylinder engines, which in 1874 (according to a report from M. Sabattier, the Minister of Marine) were working with a Belleville boiler. Several sets of boilers had been started, both before and since, on the same plan as that of the boilers of the "Propontis," but without the defect which

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., pp. 110–113.

ruined them; and all were working well to this day. This, as also the investigations conducted by Mr. Samson, of the Board of Trade, with the "Propontis" boilers, was proof that the boilers of the "Propontis" failed through a defect in construction. The absence of communication between the steam spaces was a very grave defect in these boilers, and led both to priming and to the obstruction of circulation, which resulted in the chambers over the fires being frequently without water. Unfortunately, the gravity of these things was not understood until damage had been done.

The weight of the boilers of the "Propontis" was greater than that of other examples of this system, because the makers chose to make the entire front of the casing of heavy cast-iron plates. Although the weight of these boilers, as ordinarily arranged for merchant steamers, was a little more than of cylindrical boilers, yet they could be arranged to weigh no more; and in any case the water contained in them was considerably less, so that the total weight was no greater than in ordinary practice. It was a mistake to say that the firebrick tiles, which were bolted to the inside of the sheet-iron casing, and which formed its lining, worked loose at sea. In all the examples of these boilers such a result had never been experienced, and any individual pieces which were accidentally broken were easily replaced.

The new design, which he had patented, was not proposed to meet defects in previous plans, because these were working successfully; but in order to provide an arrangement suited to the small height available under the shot-proof decks in vessels of the Navy, and where low space was for other reasons all that could be had. The arrangement of forced combustion was more than a mechanical stoker, as this was generally understood, and it enabled him to do without an ashpit under each boiler, besides affording the advantages in combustion to which he had referred.

With the Author's concluding paragraph he was sure that many who were interested in this subject would cordially agree. Apart from the importance of the subject considered scientifically, the fact that a sum amounting to from £100,000 to £200,000 was spent annually on boilers in the Navy alone was enough to show that the interests involved in it were large. He ventured the suggestion that a committee to investigate and report upon designs, as well as for the supervision of boilers, would be of great public service, and would be a valuable auxiliary to the constructive department of the Admiralty.

Mr. Flannery, in reply to observations communicated in writing through the Secretary, subsequent to the reading of the Paper, remarked, through the same medium, that, although some of these contributions were important, they did not demand a lengthy reply. He would first observe, however, that Mr. Cowper had been disappointed that the Author had omitted to advocate some special designs of boiler working at a definite range of very high pressure; and that he had confined the Paper principally to the consideration of marine boilers. So experienced an engineer as Mr. Cowper might have been expected, while joining in the discussion, to have supplied the deficiencies of which he had complained; but, beyond a passing allusion to Spiller's boiler, he had not done this. The statements made by him to the effect that boilers of 30 per cent. above the average weight should be proved to have great compensating advantages before being used at sea; that boilers that primed seriously on the slightest provocation were "not safe in ships;" that great injury was done to boilers from unequal temperature at top and bottom, and other statements of the same kind, could not be regarded as novel or valuable contributions to the discussion. Mr. Cowper suggested that, although only trifling alterations might have been necessary to make certain designs of tubulous boilers safe, yet the proper remedy was the construction of a tubular boiler without confined spaces. It was, however, difficult to see how this construction was possible. His opinion that engines had not been attended to with more success than boilers would, no doubt, be changed upon an inspection of the engines at the Paris Exhibition. There refinement had been added to refinement to produce economy by expansion in the cylinder; while the fact of the Admiralty re-appointing a Boiler Committee showed that much yet remained to be understood as to the construction of boilers. The experiments upon steel joints, detailed upon the authority of Mr. Knight, must be regarded as a valuable contribution; and, taken in connection with the data given by Mr. Parker at a meeting of the Institution of Naval Architects,[1] might be said to show nearly all that could be learned by experiment as to the comparative strength of butted and lapped steel joints. The results obtained by Mr. Parker, especially as to the increased percentage of loss from the punching of steel plates, as the thickness increased, were confirmed by the experiments which Mr. Knight had now made public. Mr. Marten's remarks upon the economy to be gained by having the

[1] *Vide* Transactions of the Institution of Naval Architects, vol. xviii., p. 334.

coolest water close to the coolest gases, and the hottest water and the steam close to the hottest gases, were very pertinent to the subject. His arrangement was exceedingly ingenious, and seemed likely to extract as much heat from the gases as was possible, consistently with the proper amount of chimney draught. It did not appear, however, that this arrangement was essentially different from that of a powerful feed-water heater attached to the boiler. Unless great care was taken that steam was not generated in the smaller, or feed heater, portions of the boiler, they would be dangerous. By judicious arrangements of the flues, as shown in Fig. 3, this objection might be met; but there must still remain considerable circulation of the water in the larger or main portion of the boiler. The experiments related by Mr. Phillips on the question of corrosion in high-pressure boilers might be regarded, when coming from that gentleman, as a proof that, upon the question of longevity, Mr. Perkins was adopting the proper construction; and that, if it were proved that in large machinery lubrication could be dispensed with by his system, he had solved the question as to the preservation of high-pressure boilers. Mr. F. J. Rowan had charged the Author with inconsistency, because, while advocating a cylindrical form as the best for strength, he had also expressed approval of the Watt boiler with its rectangular boxes at the ends of the tubes. In this, however, there was no inconsistency, because, although the rectangular form, even when stayed, was not the most suitable for strength, yet, when other considerations necessitated its adoption, it might properly be used. In the Watt boiler, the advantages of the rectangular box forming a chamber common to the horizontal tubes, and allowing easy access to them, was so great, that its use was perfectly justified, provided due care was taken in the arrangement of the stays. There could be no doubt that Mr. Rowan's arrangement to regulate the current of the heated gases was capable of producing the best result by making them strike at an angle against the water tube. He had not suggested that the use of vertical tubes was incompatible with a proper arrangement in this respect. The specimens of water tubes alluded to as being in the possession of Mr. Parker could not be said to prove that horizontal tubes were more liable to deposit than vertical tubes, unless it were shown that the arrangement in the boiler was such as to cause the extra deposit in the horizontal tubes to be due to the horizontal position, and to that alone. If, for example, two horizontal water tubes were connected by several vertical tubes, it was to be expected that the deposit of scale would be greatest in the lower horizontal tube; but this was entirely due to the position of the horizontal tube in relation to the others. If it were one of a set of horizontal tubes, acted upon by a current, the tendency to deposit would not be so great. The question of weight was of the greatest importance in connection with marine boilers. Mr. Rowan was wrong in assuming that the Author's statement as to comparative weight did not include the water in each case. In three instances that had come under his notice he had found the weight of the tubulous boiler, with its water and fire-brick casing, to be excessive; but the use of sheet iron and charcoal casing would no doubt much reduce the weight.