having natural draught with No. 23 having forced draught, the former for rather less power had seemingly two double-ended boilers, entailing two stoke-holds, double mountings and fittings, and a larger number of men. The latter had only one boiler with only three furnaces, one stoke-hold, and much less dead weight in the boiler compartment, giving to the ship a corresponding increase in freight capacity; there was also a substantial saving in fuel of 14 per cent., which in some cases was even exceeded.

Mr. Thomas L. Miller wrote that, under the head of feed heating, figures were given in page 57 to show the economy of taking steam for this purpose from the high-pressure or low-pressure receiver; and it appeared to be concluded that the economy, as far as the boiler was concerned, was due simply to the smaller number of heat units required to be put into the water in order to convert it into steam. In addition, however, to the reduction in the number of heat units taken up by the water, he was of opinion that there was a further economy due to increased efficiency of the heating surface, as had been shown clearly by some experiments which he had himself conducted. In these experiments water had been passed at a given velocity through tubes surrounded by steam at a pressure of $6\frac{1}{2}$ lbs. per square inch above the atmosphere and a temperature of 231° Fahr.; and it was found that, by increasing the temperature of the water passing through the tubes, the efficiency of the heating surface was increased to a marked extent, as seen from the following figures:—

	Fahr.	Fahr.	Fahr.	Fahr.
Temperature of water before entering tubes .	43°	48°	81°	$157\frac{1}{2}$°
,, ,, ,, on leaving tubes . .	212°	212°	212°	212°
Mean temp. of water passing through tubes .	$127\frac{1}{2}$°	130°	$146\frac{1}{2}$°	$184\frac{3}{4}$°
Difference from temperature of steam . .	$103\frac{1}{2}$°	101°	$84\frac{1}{2}$°	$46\frac{1}{4}$°
Evaporation, lbs. of water per hour per square foot of heating surface . . .	$20\frac{7}{8}$lbs.	25 lbs.	$26\frac{1}{2}$ lbs.	$30\frac{1}{2}$ lbs.
Heat-units absorbed per hour per square foot of heating surface and per degree of difference of temperature . . .	units. 381	units. 417	units. 484	units. 780

In practice he had also noticed the same effect. In one particular instance a boiler of locomotive type, fed with cold water from the town mains, had been unable to supply steam enough; but on heating the feed-water by means of a coil in the feed-water tank with steam taken direct from the boiler, no difficulty had been experienced in keeping up the required supply of steam. This instance was similar to the concluding example given in page 57 of the paper, and clearly pointed to the fact that the plan there referred to did involve economy of fuel, for the reason indicated by the foregoing figures.

Mr. Blechynden regretted that examples were not conveniently at hand for comparing the economical results of the closed stoke-hold and under-grate systems of forced draught. It would be seen, however, from Mr. Laird's remarks, as well as from his own reply to Mr. Gray, that Mr. Bruce was wrong in the assertion, which moreover was not supported by figures, that with closed stoke-holds any increase of power beyond that due to natural draught had to be obtained regardless of economy of fuel. But the closed stoke-hold had its disadvantages, to which most engineers were quite alive.

With regard to Mr. Miller's interesting notes on feed heating, it appeared to him that his experiments on the rate of transmission of heat through the sides of a tube would be well worth repeating in the light of the experiments made in 1874 by Mr. B. G. Nichol, of Newcastle-on-Tyne, for determining the rate at which heat was transmitted through a condenser tube, with a view to obtaining exact data for proportioning the surfaces of condensors ("Engineering" 10 Dec., 1875, page 449) Those earlier experiments might be regarded as identical with Mr. Miller's, inasmuch as water was passed through the inside of a tube, and was heated by steam outside; and the experiments were made with the tube placed both horizontally and vertically. The results went to show that the amount of heat transmitted through the walls of the tube per estimated degree of mean difference of temperature increased considerably with this difference. For example:—

	Vertical tube.			Horizontal Tube.		
Estimated mean difference of temperature between inside and outside of tube	Fahr. 128°	Fahr. 151·9°	Fahr. 152·9°	Fahr. 111·6°	Fahr. 146·2°	Fahr. 150·4°
Heat-units transmitted per square foot of surface per degree of mean diff. of temp.	units. 422	units. 531	units. 561	units. 610	units. 737	units. 823

These results were exactly contrary to Mr. Miller's. In Mr. Nichol's experiments the mean differences of temperature were estimated on the assumption that the rate of transmission was proportional to the difference of temperature on the two sides of the plate through which the heat passed; and this was evidently incorrect, and inconsistent with the results of his trials. In Mr. Miller's experiments the mean difference of temperature was estimated by taking the arithmetical mean between the initial and final differences; and this must also be incorrect, if the rate of transmission followed any regular law at all. These inaccuracies, however, would not account for the variation between the results of the two experimenters. Having himself been present when Mr. Nichol's experiments were made, he naturally placed some reliance upon the care with which they were carried out; and he was therefore unable to assent to the doctrine that heating surface increased in efficiency with decreased difference in temperature between the heating and the heated fluid. The increased efficiency of the locomotive boiler with the feed heater described by Mr. Miller might perhaps be accounted for by the heated feed preventing priming, as he had known to happen in other cases.

DISCUSSION.

Mr. Hector Kidd, in opening the discussion, believed that they would agree that the paper was a most valuable one, which would often be referred to on many important matters in marine engineering for many years to come. The author had treated the whole question from beginning to end in an exhaustive and masterly manner. In regard to the statement that for some years past "the boilers built for the Royal Navy have had their shells made 18 per cent. thinner than required by the Board of Trade and *Lloyd's* rules," stated in another way it meant that the factor of safety had been reduced from 5 to 4·1,

$$\therefore \frac{100 - 18}{100} \times 5 = 4{\cdot}1$$

That was assuming that the factor of safety was 5 before the reduction of 18 per cent. in the thickness of the shells, and that the test pressure had also been reduced from double the working pressure to 90 lbs. above it. Now this figure, instead of being used as a constant for all pressures, should be expressed in a percentage of the working pressure, and this percentage might be fixed at 50 per cent. above the working pressure, as with that amount of test pressure the load on the rivet seams would be 37·5 per cent. of the breaking load when the factor of safety was 4, and 30 per cent. of the breaking load when the factor of safety was 5. These percentages were dangerously near the point at which the slipping of the joint took place, as shown in the experiments conducted by Professor Kennedy for the "Research Committee" on Riveted Joints in 1885. If a test pressure of double the working pressure was applied to a test pressure of double the working pressure was applied to a boiler the load on the joints when the factor of safety was 5 was 40 per cent. of the breaking load, and if the factor of safety was reduced to 4·1, as suggested in the paper, the load on the joints would be nearly 50 per cent. of the breaking load. The following figures from the results of Kennedy's experiments to determine the percentage of breaking load at which slip began :—

Lap Joint ...	$\frac{3}{8}$ in. Plate,	23 per cent.,	Hand Riveted.	
Butt Joint ...	„ „	30 „	„	„
Lap Joint ...	$\frac{3}{4}$ in. „	21·2 „	„	„
Butt Joint ...	„ „	12·9 „	„	„

With hydraulic riveting the figures were :—

Lap Joint	$\frac{3}{8}$ in. Plate,	50·4 per cent.
Butt Joint	„ „	66·8 „
Lap Joint	$\frac{3}{4}$ in. „	33·7 „
Butt Joint	„ „	34·0 „

From these figures it would be seen that a test pressure of double the working pressure was too high for $\frac{3}{4}$ in. plate, even when the boiler was built with a factor of safety of 5. The reduction of the test pressure on new boilers was a matter which might be wisely adopted by the Board of Trade authorities.

With reference to the principle of forced draught, the advantages to be gained by its adoption were so numerous that it seemed only a question of time when it would be the general practice for both marine and land boilers to be fitted with one or other of the systems now in use. The economic and efficiency balance sheets, as shown by the figures quoted in the paper, were of a very cheerful character for steam-ship owners, and also for steam users; and not less so for the engineers in charge of the boilers, as it would give them greater control of the steam pressure when unfavourable winds were blowing, and would also enable them to make regular passages even when using coal below the average quality. The economic balance sheet showed a gain of 15 per cent., and the efficiency of the boilers had been increased to about 30 to 40 per cent. over that obtained by natural draught. Comparing, for instance, the two steamers represented by Nos. 11 and 23 in Table 5, the former with natural draught using 14 per cent.

more coal, and indicating 60 horse-power less, with nearly double the heating surface in the boilers. The difference in first cost between two boilers and one boiler, and the maintenance and depreciation account, was a strong argument in favour of using forced draught. It was very satisfactory to learn from the remarks of so good an authority as Mr. W. H. White (page 84) that the discredit which had fallen upon forced draught was mainly due to the faulty design of the boilers. The question of heating the feed water to as high a temperature as the water in the boiler before they were allowed to mix deserved the greatest attention from engineers as the benefits to be gained by doing so were: 1st, obviating the strains on the boiler by unequal expansion through the introduction of the feed water at a temperature much below the water in the boiler. The intensity of the strains set up by the introduction of cold feed water into the boiler could be figured out by assuming a stress of one ton per square inch for every 15° difference of temperature, taking the case of a boiler carrying 150 lbs. pressure, and the feed water at 150°

$$\left(367^\circ - 150^\circ = \frac{217}{15} = 14\tfrac{1}{2}\right)$$

thus the strain caused by the difference of temperature was nearly $14\frac{1}{2}$ tons per square inch. 2nd.—The prevention of scaling and pitting by the precipitation of the impurities through the agency of heat. 3rd.—By trapping all oil or grease which might find its way into the feed water. 4th.—By a saving of fuel of from 10 to 15 per cent., and an increased steaming capacity of the boiler. On page 56 the author stated that the object of heating the feed was to secure greater economy of fuel, but that heating the feed water by any of the various methods in use for that purpose did not, in principle, involve economy of fuel. In this latter statement he (the speaker) could not agree. It was unnecessary to attempt to discuss the thermo-dynamic principle by which the economy was brought about, for as a matter of fact, a number of theories had been advanced to explain the reason, and had all failed more or less, to make the matter quite clear. There were, however, the results of a number of careful trials on a large scale, which had established the fact that there was an economy of from 10 to 17 per cent. in fuel to be gained by feed heating. A trial made with a feed heater fitted in the steam space of a compound boiler showed a saving of 15 per cent.; this boiler contained 1,000 square feet of heating surface, and was evaporating about 350 gallons of feed water per hour; the temperature of the feed water was 136° Fah. These trials only lasted two days, and it was considered advisable to make a more exhaustive test before adopting the principle on a large scale, and also to test its efficiency with feed water at about 180° Fah. The second trials with the apparatus lasted about six weeks. The boiler was under steam day and night during the period; the feed water was carefully measured, and was fed into the heater at a temperature of 176° Fah.; the coals were carefully weighed, and the results proved a saving of nearly 12 per cent. During the trials the boiler fitted with the heater supplied steam to two engines, and the pressure was maintained fairly constant at 70lbs. per square inch when the heater was in use. When the feed was changed from passing through the feed heater to feeding in the ordinary way, the boiler could not supply sufficient steam to keep the engines going at their full power, and it was found necessary to light up another boiler to assist it. Experience had proved beyond a doubt that heating the feed water increased the steaming power of a boiler. In several steam tugs and launches which had been fitted with heaters, the drivers report that they generated steam easily with it, whereas without it they could not keep a full head of steam, and the engineers' report showed a saving in fuel of over 10 per cent. The trials recorded on page 108, by Mr. T. L. Miller, showed that the higher the temperature (until it reached the temperature at which evaporation took place) of the feed water, the more readily it absorbed heat from the heating surfaces, and experiments made by Bramwell, Anderson, Clark, and others, showed that water while being heated between 80° Fah. and 212° could only absorb one-third of the heat that it was capable of doing at the boiling point. Those of us whose duty it had been to stand by boilers while getting up steam must be aware that the temperature and pressure increased slowly at first and then at a uniformly increasing rate, until the point of blowing-off was reached. The explanation of this fact was due to the increasing absorbing power of the water as its temperature is increased. The author quoted the results of some experiments carried out by Mr. Nichol, in 1875, expressed some doubt as to the correctness of the figures given (page 110), but he (the speaker) considered the other figures in connection with these experiments should have been given, as they threw quite a different light on the matter. Taking the figures for the vertical tube trials—

	Fahr.	Fahr.	Fahr.
Estimated mean difference of temperature between inside and outside of tube ...	128° ...	151·9° ...	152·9°
	Units.	Units.	Units.
Heat units transmitted per square foot of surface per degree of mean diff. of temp.	422 ...	531 ...	561
	Ft.	Ft.	Ft.
Velocity of condensing water in feet, per minute	81 ...	278 ...	390
	Lbs.	Lbs.	Lbs.
Pounds of condensed water used per lb. of steam condensed	12·6 ...	29 ...	37·7

Mr. Nichol, in summarizing his experiments, attributed the increase in the absorption of heat by the condensing water to heat due to the rapid circulation of water through the tubes. Reading the experiments in this way they seemed to confirm the results obtained by Mr. Miller, as in each case the increased power of absorption of heat was caused by the increased circulation of the water, brought about in Mr. Miller's experiments by an increase of temperature in the water, and, in the other case, by an increase in the velocity of the water over the heating surface.

Mr. L. C. Auldjo could not agree with the author's views on the subject of economising of fuel by feed heating, as his (the speaker's) experience with the "Acme" feed water heater, which was nothing more than a pipe taken into the steam space of the boiler, and through which the feed water was circulated and thereby raised to the same temperature as the steam before being allowed to mix with the water in the boiler, had shown a saving of from 10 per cent. and upwards. It did appear paradoxical that such should be the case considering that the heat for raising the temperature of the feed water was abstracted from the steam, but economy was no doubt brought about by the much more perfect circulation which resulted when a boiler was fed with water having the same temperature as that contained in it. Regarding the defect which existed in the ordinary link motion, and resulted in an unequal distribution of steam on linking up, he wished to remind members that this difficulty had been entirely overcome in the gear designed by Mr Gibson by the position of the points of connection between the eccentric rods and link.

Mr. A. D. Marshall was of the opinion that a feed heater was quite as necessary as a surface condenser with modern marine engines, but he failed to see how the adoption of the "Acme" heater could result in a saving of fuel; it was no doubt a good one, and a special feature was that it took no space in the engine room. He considered that some attempt should be made to trap some of the waste heat which passed into condenser and also up the funnel.

Mr. A. Christie considered that the thanks of this Association were due to Mr. Cruickshank for having brought a paper of such importance under their notice. It seemed to him to be very desirable to look backwards occasionally in order to see what progress had been made in our profession, and to spur us on to further action. During the last decade a very decided advance had been made in the way of steam economy, which in turn allowed vessels to run long voyages at a higher rate of speed or to run at the old rate with a larger margin of profit. At the beginning of the last decade the fastest ship on the Atlantic was the "Arizona," having engines of about 6,000 I.H.P. Then came the battle for the supremacy of the Atlantic. In 1881 the "Alaska," "Servia," and "City of Rome" came on the scene. Each of these boats had engines of over 10,000 I.H.P., and each of them broke the record; but since then the advance in marine engineering had enabled us to build steamers far surpassing their speed, and having engines of over 20,000 I.H.P. This, he thought, had only become possible by the great difference in coal consumption and reduced weight of machinery for a given power. In the early seventies, Douglas and Grant, of Kirkcaldy, built a set of triple expansion engines to the designs of Mr. A. Taylor, of Newcastle-on-Tyne, and were, he believed, the first triple expansion engines afloat. They were of the two-crank type, having the high and intermediate cylinders tandem, as illustrated in the paper as the "Clarendon," which vessel was engined by the same firm, and, he thought, from the same patterns. But it was not until about 1884 that triples began to come into general use, some being successful and some comparative failures, so that it is really from that date that the great strides we have made in the economy of fuel might be reckoned. So far as the outward appearance of the usual run of triples was concerned there was little to distinguish them from the three-cylinder compound, if we except those fitted with radial valve gear. Along with the three-crank triple came the rush on radial valve gears in order to save end room and to have four-crank shaft bearings instead of six. Nearly every maker had his own particular "fad," but the majority of these had died a natural death, and the remainder would have a hard struggle to hold their own against the good old link motion. The number of wearing parts was against them, and a very little wear on each puts the valve setting a long way out. The adjustment was also very difficult; in fact, it required a fairly expert engineer to tell what was wrong, and the chances were he could only find it out by carefully gauging all the parts with the gauges supplied by the manufacturers. With the link motion any engineer could adjust or alter the valves with very little trouble, hence, he thought the old gear would still remain a firm favourite.

Since 1880 a very marked change had taken place in boilers, both as regarded the material and mode of manufacture, although in general design they were almost the same. Steel had now taken the place of iron. Although at first there were some serious failures with this material, yet our steel makers had been able to cope with the difficulty, and could now produce steel equally as reliable as iron, and 30 per cent. stronger. The method of arranging the riveted joints had also been considerably modified, so that we now worked with joints having from 80 to 85 per cent. of the strength of the solid plate, instead of from 70 to 75 per cent. At first it was the practice to punch the rivet holes as in iron plates, but this was found to materially injure them; then the holes were punched about $\frac{1}{4}$-inch less in diameter, and rimered out, but now the practice was to drill all holes, so that with better material and improved workmanship we could now make boilers to stand a working pressure of 180 lbs., and be as safe as the 90 lbs. pressure boilers of ten years ago. As an illustration of the change that had taken place he would take the case of the boiler shell for the new pilot steamer now building at Mort's Dock. This shell was of steel $1\frac{5}{16}''$ thick, but if made of iron, and made as was usual 10 years ago, the shell would require to be at least $2\frac{1}{8}$ inches thick, which would be an absurdity. The author stated that the boilers for the navy had shells 18 per cent. lighter than allowed by the Board of Trade, and suggested that the Board of Trade rules should be reduced; but the real strength of the material was the strain that could be put on it without injury. This, in the case of boiler shells, reduced the factor of safety from 5 to about $2\frac{1}{2}$,