Discussion.

The Chairman. The CHAIRMAN, in moving the vote of thanks to the Author, remarked that the subject of the Paper was of great importance, and The Institution welcomed a Paper of that nature, as affecting the interests of many of the members. In the latter part of the Paper the question of pulverized fuel was referred to. His own feeling was that the problem of the large boiler was big enough to occupy attention at one sitting, and that the question of pulverized fuel was really important enough to justify its treatment, say, next Session, in a separate Paper, which The Institution would welcome. The Author stated (p. 135): "The design should preferably be best suited for the ultimate development of high working pressures of 500 to 750 lbs. per square inch, and therefore riveting and welding should be reduced to a minimum, or, if possible, eliminated altogether." That introduced the question of possible manufacturing difficulties. The Author recommended that knowledge and experience should be pooled and considered by a Technical Committee. He would venture to suggest that when a pressure of 750 lbs. per square inch was being approached, and such large units were being considered, the metallurgist and the steelmaker should be consulted. Engineers knew what they required, but knew also that they could not have it without earnest consultation with the engineers and steelmakers who had to produce the drums and plates, and to provide for the elimination of riveting. Both in regard to temperature and pressure it appeared to be inevitable that, if anything like the magnitude the Author had in view was reached, engineering and metallurgical difficulties would be encountered, and he thought the matter would be very warmly taken up and studied by those whose business it was to look into such things. It was within his knowledge that some boiler-makers of eminence had already specialized in that direction and had put great pressure on steelmakers to tackle questions of the kind. Therefore, whilst what he suggested had been done to a modified extent, he thought still more would have to be done to meet what the Author had in view. He felt that those matters would have to be considered in the light of manufacturing difficulties as well as in the light of the technical perfection at which the Author was aiming.

Mr. Patchell. Mr. W. H. PATCHELL remarked that he had read the Paper with considerable interest, and it had left him rather wondering whether

Mr. Patchell.

it was an advisory Paper, and from what angle it had been written. He would confine his remarks to what had been accomplished. For 25 years he had been advocating large boilers. When he started in 1900 there were limitations: mechanical stokers could not be obtained to cope with the big boiler, and the necessity of pure water was not then appreciated. Mr. Patchell then traced briefly the history of the large boiler, illustrating his remarks with lantern-slides. He stated that in 1901 he installed a horizontal-tube boiler of 8,100 square feet heating-surface in Bow generating-station. That was larger than was usual in those days. In 1903 he installed an "Upright" boiler [1] of 21,700 square feet heating-surface and 100,000 lbs. hourly evaporative capacity. He paid his first visit to America in 1905, taking with him photographs and particulars of that boiler, which he showed to friends in Detroit, Chicago, and New York. Mr. Alex. Dow, of Detroit, after examining the Bow boiler, installed a W-type Stirling boiler in 1909 at Delray No. 2 station, with 26,654 square feet of heating-surface. Mr. Dow had the advantage that stokers were then more or less developed, and he put in what was called an "underfeed" or retort-type stoker. The Connors Creek, Detroit, station was equipped in 1920 with nineteen W-type Stirling double-fronted boilers of 23,654 square feet heating-surface. At Mr. Henry Ford's River Rouge works Ladd boilers of 26,470 square feet heating-surface, arranged for firing with pulverized fuel, gas, and oil, were installed in 1920. Mr. Dow went a shade larger for the Congress Street station at Detroit, and in 1921 adopted a Connelly double-fronted boiler of 29,820 square feet heating-surface, which was essentially of the same type as the Stirling boilers at Connors Creek. Colonel Mercier, who designed Gennevilliers station in 1921, inspected the Detroit works, and adopted both Babcock and W-type Stirling boilers, the latter being similar to those designed by Mr. Dow. At Cahokia, St. Louis, a rather smaller Babcock boiler of 18,010 square feet heating-surface was installed in 1923, equipped with pulverized-fuel plant. At Lakeshore, Cleveland, there were two Stirling W-type boilers, with 30,600 square feet heating-surface, set as one boiler. The unit worked as one boiler but, strictly speaking, was made as two boilers for economic reasons. American engineers were now trying to standardize the design of large boilers. When he was in America in 1924 the boiler-plant of the Avonbeach station was in course of design, and a boiler large enough could not be supplied, except at an exorbitant price, therefore an arrangement similar to

[1] Journal Inst. Elec. E. vol. xxxvi (1905), p. 71.

Mr. Patchell. that at Lakeshore was adopted. The Author would be interested to learn that the 8,100-square-foot boiler installed at Bow nearly 25 years ago was not an ordinary sectional boiler like the Babcock: there were three box headers at the front and four at the back. The bottom back header had an independent supply of water; thus tubes immediately over the fire obtained a supply direct from the drum. There were also two stokers set at right angles in that boiler—a design that had been re-introduced. The following figures, contrasting the operation of Delray and Connors Creek stations, demonstrated the advantages of the big boiler. At Delray 5,600 kilowatts, and at Connors Creek 12,800 kilowatts were produced per boiler. The output of Delray was 1,900 kilowatt-hours per man-hour of boiler-house staff, and at Connors Creek it was 3,600 kilowatt-hours—nearly twice as much. Taking the turbine- and boiler-rooms together, the output at Delray was 1,300 kilowatt-hours per man-hour, and at Connors Creek 2,500, or nearly double the output per man-hour. That was not done by nursing one station at the expense of another: the load-factor at Delray was 52·7 per cent., and at Connors Creek 49·9 per cent. The boiler-house of the Trenton Channel station at Detroit contained eight Stirling W-type boilers supplying three turbines each of 50,000 kilowatts. The boiler-house floor was 45 feet above ground-level, and the roof with the precipitation-house was 130 feet above ground-level. The boilers could steam at 400,000 lbs. per hour, and carried that load perfectly well. The limit at present was not the boiler, but the fan handling the induced draught. The drum plates of those boilers were $1\frac{3}{32}$ inch thick, of "straight" carbon steel; and he was afraid to allow the boiler-maker to handle anything but "straight" carbon steel under present conditions. He felt very strongly that nickel-steel and other alloy steels should only be heated under the supervision of a metallurgist. With regard to pressure, it was on record that the first President of The Institution was engineer of St. Katherine's dock, where Jacob Perkins, in 1827, had a boiler working at 800 lbs. per square inch with an engine of 8 inches bore and 20 inches stroke. At Boston, Mass., a boiler for 1,200 lbs. per square inch working-pressure had been installed. There were two 30,000-kilowatt turbo-sets working at 300 lbs. per square inch pressure, and one 2,500-kilowatt set working at 1,100 lbs. The exhaust from the high-pressure set passed through a reheater in the boiler and then into the ordinary steam main supplied from cross-drum boilers working at 375 lbs. per square inch pressure and 700° F. The high-pressure boiler was of the cross-drum type, the drum being a forging 34 feet long, 4 feet inside diameter, with $4\frac{1}{2}$-inch thick walls, increasing to

$8\frac{1}{2}$ inches at the manholes, and weighing 88,475 lbs. (Mr. Patchell described the forging of the drum at Midvale[1]). That drum showed what could be done when high pressures were required; but he did not call that boiler-making: it was special work, and engineers would have to go very cautiously with higher pressures. Mr. Patchell.

Engineer Vice-Admiral Sir ROBERT B. DIXON, K.C.B., thought that the designer of the land boiler could learn something from the marine-boiler designer, as he was quite sure the latter could learn a great deal from land practice. The Author referred to boilers having an evaporative capacity of 100,000 lbs. per hour, and seemed to think that that was rather a high figure. He could only say that in marine practice it was quite common; there were many boilers of more than 100,000 lbs. hourly capacity, and there were some up to 150,000 lbs. He need hardly say that their size was possibly one-quarter to one-eighth of that of the corresponding land boiler. In connection with large boilers the question of superheat required special consideration. He imagined that at times such boilers would work at low duty, and, if that was so, it was rather a problem with the present type of heater to get a constant superheat. A separately-fired superheater would obviate that, and he would like to hear boiler-makers' views on that point. He agreed with the Author that 7 lbs. per hour evaporation per square foot of heating-surface was extraordinarily low. In marine practice 20 lbs. per square foot was not unusual. With such high-duty boilers, however, pure feed-water was essential. It was his experience that, if there was any salt in the water and a deposit was formed, overheating of the boiler-tubes was inevitable. With carefully-designed circulation there should be no difficulty from priming at high rates of evaporation. The question of high pressures had been referred to. Mr. Patchell had spoken very lightly of 1,200 lbs. per square inch, but Admiral Dixon thought high pressures should not be adopted without very careful consideration. Many difficulties were met in connection with high pressures. The increase of pressure from 150 to 300 lbs. per square inch caused considerable trouble about 25 years ago in the Navy. When the pressure was raised from 300 to 700 or 1,200 lbs. many new difficulties would be introduced; and he did not look forward to such high pressures on H.M. ships with any great pleasure. It had been found in the Navy that it was advisable to put the feed-water into the steam drum of the Yarrow boiler. Originally, it was put into the water drum, with the result that there was heavy corrosion of the tubes, due to the air being liberated on the intro- Eng.-Vice-Admiral Sir Robert Dixon

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[1] See Proceedings I. Mech. E. 1924, i, p. 250.

Eng.-Vice-Admiral Sir Robert Dixon duction of the feed-water. With the modern practice of heating the feed-water, that would be lessened, but he thought the better practice was to put the feed-water into the steam drum. On p. 148 the Author stated that actual experience showed that there would be no scale with foul feed-water. In the Navy there had been a great deal of experience which was entirely contrary to that statement. If there was the slightest trace of salt in the feed-water, almost instantaneously heavy priming followed, and unless the leakage of salt water was stopped, the tubes would get overheated through the presence of scale. That applied to all water-tube boilers working at high duty. Unfortunately, the Navy had had considerable experience of that nature.

Mr. Hamilton Gibson. Mr. J. HAMILTON GIBSON said he would confine his remarks to the question of soot-blowers, which the Author dismissed in a very few lines. He thought that in boilers of the size under discussion, which it was impossible to clean by hand, it was extremely necessary that such fittings should be used. The Author stated that the use of soot-blowers was well justified; but Mr. Gibson was inclined to say that no large boiler should be designed without due provision for such blowers; there was no justification for omitting them. The Author also referred to the reduction of flue temperatures as being 100° F. after each blow-out, but Mr. Gibson had experienced very much greater differences than that, even 200° and 250° F. Taking the average difference in temperature between the combustion-chamber and the flue at about 2,000° F., a drop of 100° F. meant a 5-per-cent. gain, either as increased evaporation or less fuel burned. Soot and dust was referred to by the Author as being blown out into the atmosphere, but that, of course, was bad practice. A good many power-station engineers knew, to their sorrow, that if they did discharge large accumulations of soot into the atmosphere they were apt to have trouble, especially with the Medical Officer of Health, or some other authority. The remedy was to blow more often, and in any well-designed boiler there should be soot- or dust-pockets, so that the stuff could collect and be withdrawn periodically. It was important to see that the soot as it was blown was not scattered all over the boiler, because then as soon as the blow was finished it was merely deposited again on the tubes. In an extended run of 1,000 hours he had seen boilers really cleaner at the end than they were at the start—due entirely to the periodical operation of efficient soot-blowers.

Sir James Kemnal. Sir JAMES KEMNAL observed that the question of the large boiler had always been taken into consideration, and there was no difficulty whatever in making sectional boilers of any size; but in

Sir James Kemnal.

the case of a non-sectional boiler, such as the Stirling or Yarrow, there was much more difficulty in the construction, particularly in connection with superheaters, air-heaters, economizers, and feed-heaters, which were essential to the boiler. The making of such boilers of any power for ordinary pressures was comparatively easy. To deal with the high pressures that were asked for nowadays in connection with very large units was quite another matter, and required not only great skill but also special plant for manufacture. He was experimenting with pressures up to 800 lbs. per square inch at present, but in going beyond that it was necessary to adopt the method of construction that Mr. Patchell had described—a seamless drum made as a gun. Some large boilers were on order for the municipality of Amsterdam, in connection with which such drums were being made in Germany. The German munition-makers were turning their plant to account in making such things. So far no difficulty had been found in the construction. [In reply to a question put by the Chairman, Sir James Kemnal stated that one British firm was willing to make such drums, but not of the length required.] The boilers for which the drums were required were guaranteed to produce 70 tons (154,000 lbs.) of steam per hour, which compared very well with American practice. The steam had to be produced at a pressure of 40 atmospheres, or nearly 600 lbs. per square inch, and in addition the boilers had to provide a superheat of 700° F. The firing was with pulverized coal. The furnaces were provided with water walls, and all the latest improvements were incorporated. A single unit of the boiler cost close on £35,000, so that it would be seen there was a great development in price as well as in boiler size. One notable installation his firm was carrying out at the present time was an installation near Ghent, Belgium, in which the boilers were to work at a pressure of 800 lbs. per square inch ; the steam was to be taken through steam-turbines which were of considerable power, with wheels about 12 inches in diameter, and the exhaust steam would then feed the existing turbines. A corresponding proportion of the old boilers, which worked at 300 lbs. pressure, was being put out of use. With regard to the question of soot-blowing, he knew very well from experience that after using a soot-blower the temperature fell at least 100° F. The objection to it in a city was the emission of small particles of soot, but that objection had to be put on one side having regard to the advantages and efficiency directly due to the soot-blower. When considering the question of the capacities of boilers generally, the fact should not be lost sight of that all boilers under the same conditions gave the same results. As long as two boilers had the same degree of baffling, worked at the same

Sir James Kemnal. pressure, and had the same heating-surface, the same end temperature, and the same rate of absorption, the results were bound to be the same. But it was not for that reason alone that a boiler of a certain type should be chosen; a boiler should be chosen for mechanical reasons altogether. It was quite true that with pulverized fuel the most perfect combustion could be obtained, but the mechanical stoker ran the pulverized-fuel system very close. With pulverized coal there might be an increase in efficiency of 5 per cent., but against that had to be put the immense cost of pulverizing, the space taken, and the increased capital cost. It would be interesting to the members to know that the capital cost of the arrangements for pulverizing amounted to just as much as that of the boiler, so that he was not disposed to favour it unduly. It was a mechanical advancement, but he thought the ultimate goal for pulverized fuel would be some form of pulverizer which could be applied directly to the furnace and so avoid all the apparatus at present necessary. It was very easy to make water walls for boilers. He remembered seeing nearly 30 years ago a ship of the Wilson Line which had a single Babcock boiler constructed with water walls similar to those shown by Mr. Patchell. In fact, there was hardly anything that had not been done before. The boiler-constructor had several things to consider—including the wishes of his customers and their pockets—so that he could not put in every refinement in every case.

Mr. Yarrow. Mr. HAROLD E. YARROW, referring to *Fig. 11* (p. 149), remarked that the Author did not think there would be any difference between the rate of circulation in the Yarrow compared with the sectional boiler; but Mr. Yarrow thought the Author had lost sight of the fact that the speed of circulation was dependent on the head less the frictional resistance, and he submitted that there would be more frictional resistance in the sectional type. He thought the Author had that point in mind when he stated (p. 136): "The Babcock boiler as at present constructed is considered to have the limitation that, if it is consistently pressed, the lower tubes adjacent to the furnace may become overheated, in consequence of which distortion and failure may result." In the Navy the boiler-tubes generally used were of much smaller diameter than those used in land boilers, the tubes in Yarrow boilers (land type) having a cross-sectional area about two-and-a-half times that of the Navy tube, and the output of the Yarrow boiler for naval purposes was two or three times that of land boilers. Sir Robert Dixon had referred to the introduction of the feed-water into the lower drum. It was the practice in land boilers to feed into the top drum owing to the risks of corrosion when feed-water entered the steel tubes;

and the same reason made the steel economizer a difficult problem in connection with high-pressure boilers and pointed to the introduction of air-heating as a good solution: it was, in many respects, a preferable means of utilizing waste gases from the boiler. Sir James Kemnal had mentioned that sectional boilers could be constructed of any size. His firm would be quite pleased to build Yarrow boilers of any size, and therefore he did not think Sir James could claim that qualification for any particular type. With regard to brickwork, in Navy practice it was very often only $2\frac{1}{2}$ inches thick. His firm had recently installed two land boilers where the brickwork was hollow; thus not only was the air heated, but also the brickwork was kept cool. That, in conjunction with a large surface exposed to direct radiation of the gases in the furnace, certainly had a great tendency to keep the brickwork in good condition. One important point in regard to boiler design was the desirability of having as large a combustion-chamber as possible, and also as much surface exposed to direct radiation as possible. He submitted that the boiler in which the heating-surface was so disposed as to absorb a considerable amount of heat from direct radiation, would certainly give more evaporation per square foot of heating-surface for the same efficiency than it would if the surface exposed to direct radiation were less. Mr. Yarrow.

Mr. C. T. A. Hanssen thought the Author made two valuable suggestions which had not been referred to in the discussion. One was for improving the circulation, which the Author stated could be done by providing a direct connection to separate headers for the lowest bank of tubes. Another was the advocacy of the high setting. He had had a good deal of experience with Lancashire boilers, from which it was possible to get excellent results by working with coal which gave very little flame and no soot. When bituminous coal was used in a Lancashire boiler, a poor result was obtained, because the flame struck against the cold surface of the boiler, and instead of the gas being burned, soot was developed. If the tubes could be raised sufficiently high above the grate, it would be possible to avoid soot altogether and obtain perfect combustion of the coal and the gas before the flame had time to strike against the comparatively cold surfaces of the tubes. He thought that in those two matters—increased circulation and higher setting—the real secret of progress in boiler-making was embodied. The admission of air should be regulated in such a way that there was no leakage of cold air into the boiler. The Author advocated one fan for pumping air into the furnace and another fan for extracting air, so as to obtain equilibrium, because it was Mr. Hanssen.

Mr. Hanssen. practically impossible to obtain an air-tight brick wall. If it were possible with the same area of heating-surface to get two or three times as much evaporation as was now usual, he thought it would be a valuable advance in the practice of boiler-making. He believed attention to the three points he had mentioned would produce a wonderful advance in boiler-efficiency and in fuel-economy.

Mr. Donkin. Mr. S. B. DONKIN thought it right to call attention to the fact that the means of improving the circulation, referred to by the Author, was the invention of Mr. R. McGregor. As that type of boiler had proved very successful in practice, it was right that Mr. McGregor should get the credit for designing it. Mr. Donkin's firm had been partly responsible for installing at Greenwich a few boilers of that design, to produce about 50,000 lbs. of steam per hour. They were able to evaporate quite easily 80,000 lbs. per hour, and at that output the rate of evaporation was about 9 lbs. per square foot of heating-surface. Sir Robert Dixon had stated that in naval boilers as much as 20 lbs. per square foot was practicable. Mr. Donkin suggested that it was possible to get those rates of evaporation, but not with the high efficiency aimed at in connection with land boilers. An efficiency of about 80 per cent. was possible with a steaming-rate of 9 lbs. per square foot per hour. If the evaporation was reduced to about $5\frac{1}{2}$ lbs. per square foot, the efficiency increased to 88 per cent., and that efficiency included the economizer. It would be interesting to know what the approximate over-all efficiency was in boilers having an evaporation of 20 lbs. per square foot per hour. Reference was made in the Paper to the fact that the Yarrow boiler was able to respond very quickly to overloads. That, no doubt, was quite true, especially in naval practice, where oil-firing was used. In land practice it was difficult to make the boiler respond quickly to the big changes of load and big overloads, on account of limitations imposed by the stoking-plant. Where it was possible to use oil firing or powdered fuel, no doubt a rapid response could be obtained. With regard to efficiency, he desired to point out that in a power-station of 100,000 kilowatts of plant, 1 per cent. increase in efficiency might, under certain conditions, with a 50-per-cent. load-factor, effect a saving of £25,000 a year. Even deducting, from £25,000, £1,000 a year for the services of an efficiency engineer, a very large margin would still be left.

Colonel Crompton. Colonel R. E. B. CROMPTON observed that the engineering of power-generation had been the main work of his life for the last 40 odd years, and, as one of those who had been responsible for the introduction of the water-tube boiler for power-stations, he

Colonel Crompton.

was naturally very much interested in the Paper. He had to confess, however, some disappointment on reading it. The Paper, however well meant, gave him very little useful information. The first two-thirds of it described various comparatively small modifications of well-known types of water-tube boiler; towards the end was a description of the Yarrow type; but only a few pages were given to the description of what had been accomplished with super-size boilers. What he, in common with all power engineers, wanted to know was: what economical advantage was to be gained, or likely to be gained, by their introduction. He remembered that, when he first began to use boilers to generate steam for electric power, he was taken to task by the boiler engineers of that time for not using the well-known Lancashire type. It was then said that there were a sufficient number of new problems to deal with outside the boiler-room, without adding to them the uncertainty of using the comparatively untried water-tube boiler. He believed that all power engineers were substantially in agreement with him in stating that the Babcock type, or variations thereof, had been the chief boiler-room feature in great power-stations. He regretted to see that the Author omitted from the historical part of his Paper the fact that the improvements which he described—increasing the distance between the incandescent surface of the fuel and the lowest row of tubes, and modifications in the position of the first fire bridge so as to get as large a surface of the tubes as possible exposed to the direct radiant action of the fuel—were really worked out by two engineers at the Wood Lane station, namely, the late Mr. H. M. Miller and the present engineer, Mr. C. M. Bennett. He remembered well how hard they had worked to proportion correctly the coking- and ignition-arches. They ought also to have the credit for improving and developing the chain-grate stoker. Those developments were taken as a matter of course, but it was only fair to the two engineers in question to say that the Author was wrong in stating that those great improvements, which had done so much to raise the evaporative efficiency of the type of boiler under consideration, were of recent introduction. The Paper devoted too much space to matter which was merely descriptive of various types and which did not give the quantitative information that power engineers now desired to have before them. The Author did not attempt to give the actual gain in boiler-efficiency that could be expected by the use of such large units. For, although he stated that in America an all-round increase from the present 17 per cent. up to 24 per cent. was expected, he did not attempt to show how much

Colonel *Crompton.*

of that would be due to the boilers, as distinct from the turbo-generators; he hoped that the Author would elaborate this question in his reply. Colonel Crompton thought that, although a total efficiency of 24 per cent. was likely to be obtained, not more than 5 per cent. of that would be due to increase in boiler efficiency, merely as a result of increased size of units. An evaporative efficiency of 78 per cent. was often now obtained; but to increase that to 82 per cent. demanded expenditure on various auxiliaries and possibly additional cost due to the larger size of the boiler-units. However, such larger boilers and the numerous auxiliaries required to give that high efficiency were likely to be more costly to maintain; and from the financial point of view he could not look upon them without misgiving. He thought that the increased cost of attendance and maintenance, added to the extra obsolescence charge, would quite possibly cancel the small gain in theoretical efficiency. The obsolescence figure, which must be charged on to the cost of production in view of the fact that all power plant was likely to be superseded sooner or later by plant of different form and design, was the bugbear of power engineers. They had before them the example of the shipowners: a few years ago it was considered that a point had been reached in ship engine and boiler design that approached finality; but now that the internal-combustion engine was so rapidly gaining favour, prudent shipowners were obliged to consider writing off heavily from the present values of their vessels. He hoped that some means might be found to obtain the pressure required to drive existing steam-turbines by storing pressure generated by internal combustion in suitable containers. The matter was already receiving much consideration on both sides of the Atlantic, and, although he would not be sorry if such a revolution did not come in his time, no one could say that it was not likely to come during the next 10 or 15 years. It was practically certain that it would still be prudent to write off annually obsolescence sums, which would be particularly onerous if gigantic boiler-units were adopted now, which might not be worked up to their full duty for several years. Again, for safety and continuity of supply, much was to be said for the sub-division of boiler-units, since one unit could be so readily shut out of circuit without affecting the general working, and any small defect could be quickly set right; whereas if it were necessary to keep the whole unit at work, heavy and costly damage might follow. He wished forcibly to emphasize his view that mere increase of size of plant did not constitute good engineering; good engineering consisted in carefully watching all details and especially in great attention to keeping down the cost of repairs, as well as in so proportioning the plant in use to the load obtainable as to keep capital and obsolescence charges as low as possible. Colonel Crompton.

Mr. Stromeyer. Mr. C. E. STROMEYER wished to endorse what Colonel Crompton had said with regard to the Paper not containing the information which engineers really desired. In fact, it had struck him on reading through the Paper that the position of the Author was rather weak, because the arguments he used were hardly engineering arguments; he stated that there was no reason why engineers should stop at a limit of 100,000 lbs. per hour, and that the Americans had gone to 300,000 lbs. per hour; but shortly afterwards that was modified by the statement that in American boilers very high duties were employed. The standard in this country was 7 lbs. per square foot of heating-surface per hour, compared with 10 lbs. in America. Those were not engineering arguments. What engineers wanted to know was, in what way did an increased size of boiler improve conditions. He had seen several times the Barton station, where there was one of the largest units in England; but that double-ended unit of 100,000 lbs. was subdivided by an air-passage between the two portions of the boiler. He had never been able to see the advantage of tying two boilers together, because in case of tube-failure two boilers were thrown out of use instead of one. He had come to the conclusion that any accident that could possibly happen in engineering work always would happen. The tubes nowadays were more reliable than they used to be; but, when there were thousands of tubes in a boiler, he thought the possible chance of one of those tubes bursting would finally be made a certainty. In a recent case a Babcock boiler had been running for 23 years without trouble, and yet within 2 years three tubes burst. A large unit might be quite free from accidents for a few years, but he would not be at all surprised if, after a certain period, a series of accidents occurred suddenly. It was urged that the larger a boiler was made, the smaller relatively would be the radiation loss, and in a sense that was quite true; but at Barton it had been necessary to have an air-passage between the two parts of a boiler; nor could he see how American 300,000-lb. boilers could possibly be reasonably accessible without subdivisions; so that there was a practical limit to the reduction of radiation losses. It was quite evident that, if an engineer could not go beyond a certain size in regard to the several parts of the boilers, he might just as well have so many separate boilers. Then there was the question of heat-transfer. The subject did not appear to be very well understood—he admitted that he did not understand it, and he took it for granted that others also longed for enlightenment. But recent experiments

Mr. Stromeyer. on heat-transfer from the fire to the water pointed to the fact that the radiation law played a very important part. Some experiments had been carried out recently on a Stirling boiler in which the heat transferred in the first row of tubes amounted to 75 per cent. of the total heat transferred to the whole boiler, the back tubes taking up the heat by convection, and the front by radiation. The law of radiation was that the heat transferred was proportional to the fourth power of the absolute temperature, and the transfer was proportional also to the fire-surface. That meant that the heating-surface exposed to radiation was of relatively less consequence than was the intensity of the fire. It was not so much a question of the cooling-surface of the tube as of the radiating power of the fire. That was one direction in which he thought some reduction might be made in the size of boilers. The tube receiving the radiant heat must, of course, be able to deal with that radiant heat. That difficulty seemed to have been solved in the Atmos boiler—a Swedish invention—which had revolving tubes. Water was let into the tubes at one end, and the tubes were rotated at such a high speed that by centrifugal action their surfaces were coated with water. There was practically no circulation, the steam, as soon as it was formed, being driven away from the heating-surfaces on account of the force with which the water was pressed towards those surfaces. In a description of one trial of that boiler he noticed that the boiler had only 12 square metres of rotating heating-surface; 190 square metres of heating-surface in which heat was transferred by convection, and about 80 square metres of superheating surface, and yet those 12 square metres of rotating heating-surface absorbed about 40 per cent. of the heat taken up by the whole boiler. That showed that, if means could be provided for taking away the steam—and in the case mentioned the steam was at a pressure of about 1,500 lbs. per square inch and not of large volume—the heating-surface would become of less importance than the furnace-temperature. Power-stations would not have abandoned the Lancashire boiler if its size had not been limited by considerations of transport. That was not very often mentioned. He thought a diameter of 9 feet 6 inches was the present railway limit, and therefore a boiler that could be built in place was the most convenient for large units. If larger diameters were to be utilized, he did not see any reason why marine boilers should not be used. He believed that such boilers of 12 to 14 feet in diameter were installed in some factories, but it was only near seaports that their use was possible. Advocates of large boiler-units urged that they were more efficient than small units; not only was the outer surface relatively made smaller than in smaller boilers, but the walls were thicker ; that was merely a necessity on account of the greater height of the boilers, but there was no reason why walls of small boilers could not be made equally thick, and that would reduce the radiation in the same way. Designers of large boilers did not seem to mind how bulky the units became; the economizers were piled on top of the boiler, the superheater had to be accommodated, and now, with pulverized fuel, a place as big as a cathedral had to be built under the boiler, which had been reduced to relatively insignificant dimensions, the whole space being taken up by the accessories. There were other means of improving the efficiency of the boiler than by increasing its size. He had in mind two inventions, one, that of Mr. Druitt Halpin, which was now being taken up by a Swedish engineer—the thermal storer. It enabled the difficulty of the peak load to be overcome and also the necessity of having stand-by boilers, and therefore conduced to a steady and economical service. Another invention which struck him as ideal, although he did not know much about its practical working, was the Ljungström pre-heater. He had seen it at work and, as far as he could make out, there was no reason why the temperature of the escaping gases might not be reduced to 200° F. or less. The reduction of waste-gas temperature was not limited, as with economizers, on account of the necessarily high inlet temperature of the feed ; the only limit was the air-temperature. If it were possible to reduce the temperature of the waste gases as much as that, it would not matter whether the boiler was large or small. If it was intended to economize and increase the efficiency of boilers, he thought engineers should try some modern ideas rather than go in for rivalry with the Americans in connection with the big sizes of which they were so proud. Mr. Stromeyer.

Captain H. RIALL SANKEY remarked that the defect of a leaky or burst tube would be equally effective in putting out of commission either a small or a big boiler, but the chances of having a leaky or burst tube were evidently greater in a large than in a small boiler. Mr. Patchell had described the forging of an enormous drum that had had to be adopted for a large boiler working at a pressure of 1,200 lbs. per square inch, the making of this drum being a most interesting engineering job. He noticed that the Author limited his requirements to a pressure of 750 lbs. per square inch, and in such cases, no doubt, forgings of the kind described by Mr. Patchell would not be needed. Mr. Stromeyer had described another method of obviating big drums with high pressures, namely the rotating tube. In that case, with quite small tubes rotating at 300 revolutions per minute, apparently a pressure of 1,500 lbs. per square inch could be dealt with. Another solution was to increase the pressure very much Captain Sankey.

Captain Sankey. indeed, bringing it up to the critical pressure of 3,200 lbs. per square inch, which meant a critical temperature of 702° F., at which there was neither steam nor water—he would like to call it "mush." A boiler of that kind could be made like an ordinary serpentine, and he believed they had been used in Germany at pressures exceeding 3,000 lbs. per square inch for hot-water services. The Benson system adopted the same idea: the boiler was merely a serpentine working at 3,200 lbs.; then the steam was throttled down to a pressure of about 1,200 lbs. per square inch, thus producing superheat by ordinary throttling expansion, after which the temperature was further raised to 900° F. Such a boiler had been made and tried at the Willans works at Rugby with successful results. He would like to put to the Author a quasi rule-of-three sum. If the overall efficiency of a boiler (or rather steam-generator) evaporating 50,000 lbs. of steam per hour was 82 per cent., what would be the efficiency of that same boiler, merely enlarged, with no alterations, when evaporating 300,000 lbs. of steam per hour?

Mr. McMahon. Mr. P. V. McMahon remarked that he had understood Mr. Patchell to say that boilers of 300,000 lbs. capacity were in existence; that statement probably applied to America, where power-houses were of the order of several hundred thousand kilowatts output and were interconnected. In this country, however, stations of 100,000 kilowatts output were considered large, and it appeared that 300,000-lb. boilers would be out of place under such conditions. It would, he thought, be found, taking into consideration the question of spares amounting to 25 per cent., that boilers of 75,000 to 100,000 lbs. capacity would be as large as could be justified from a financial and operating point of view.

Mr. Tresilian. Mr. A. S. Tresilian observed that for working-pressures exceeding 500 lbs. per square inch the Author recommended manufacturing the drums without seams; that was certainly necessary at 800 lbs. per square inch. It had been stated that such drums could not be made in England, but his firm could make drums for pressures of more than 800 lbs. per square inch, with 851° F. final temperature, of seamless carbon-steel forgings in one piece, the drums being up to 35 feet long and 4 inches thick, if necessary. The limiting feature of high-pressure boilers was the question not so much of pressure as of temperature. When working at 851° F. final temperature, great care had to be taken not to work too near the actual yield-point of the material. For instance, superheater tubes at 920° F. would be of a dull red colour. His firm was putting up three large double-circulation boilers close to London. The water was pre-heated in the boiler itself before it was passed to the main circulating tubes, and in view of the design of the boiler generally, it was hoped to get as high efficiency when working at the rate of 15 to 20 lbs. evaporation per square foot as was obtained with a normal boiler working at very much lower rates. That might be a great advantage in boilers of normal size. The Author drew attention to the advantages of mud drums—which Mr. Tresilian agreed were good practice—and the provision of a large outlet where the steam and water came away from the back headers. The particular boiler to which he referred was designed so that the back headers of the boiler had double the cross-sectional area of the front headers. Some comparative tests were being made with the ordinary standard boiler, but results were not yet available. With regard to the Author's mention of the difficulty of meeting sudden demands of load on a boiler, he considered that that was not so much a matter of the boiler itself as of the design of the combustion-chamber and of an efficient stoker or other method of firing. With the newest type of stoker, having compartments which were distributed over practically every 2 or 3 feet of the grate, the air could be controlled almost instantaneously at any load; and it was a matter of the correct manipulation of the air-supply. With very low-grade fuels the new stokers were provided with induction zones in the first compartment so that the lowest-grade fuel could be ignited immediately it came under the gate. That was an important point when dealing with very sudden loads. Those stokers could be manufactured up to 20 feet wide—in fact, in America they were being made 24 feet wide—and the whole surface of the grate was utilized in the combustion-chamber without having any dividing walls. He did not quite follow the Author's remark (p. 158), that: "in a boiler having a superimposed water-tube-lined furnace there is little or no brickwork to heat, and it will be possible by its use to make fuel-consumption almost instantaneously follow steam-demand, and stand-by losses will practically disappear." He would much like to hear something more on that point, because it was a matter which was receiving great attention in all furnace-design, namely, the efficient cooling, or protection, of the furnace-chamber lining. With bare steel tubes in a furnace there was a tendency to reduce the furnace temperature and therefore the efficiency of the boiler, and also a danger of causing smoke, due to incomplete combustion before the gas reached the cool surface. He knew of boilers which had run for 5 years with very high combustion-chamber temperatures, and in which the tubes, instead of being on the surface of the furnace, were embedded in the brickwork; and he thought that was of great advantage, because there was no tendency to reduce the

Mr. Tresilian.

Mr. Tresilian. furnace temperature to a great extent and there was very little likelihood of smoke trouble. The question of air-heaters was also of much interest, because there were no very definite figures of the efficiency obtained with the air-heater except at high temperatures of air into the combustion-chamber. He thought the best results for air-heaters were obtained when the temperature was approximately 400° F. Very great difficulties had been experienced when air at 300°–400° F. was supplied to furnace-chambers. He was very much against exceeding 300° F., but it was only at the higher temperatures, apparently, that there was a great gain in efficiency, and a good deal more investigation was necessary before making any further statements as to efficiency.

Mr. Jockel. Mr. L. M. JOCKEL observed that the Author's statement on p. 140 that evaporation up to about 223 lbs. of water per hour per square foot of actual space occupied by the boiler would be obtained with the modern large boiler-unit, was of great importance to power-plant engineers generally. That was a very marked advance, representing an increase of approximately 70 per cent. over present-day practice, as would be evident from the following Table :—

Station.	Boiler Unit.		Working-Pressure.	Steam Temperature.	Evaporation per Square Foot of Floor-Space.
	Type.	Overload Evaporative Capacity.			
		Lbs. per Hour.	Lbs. per Square Inch.	°F.	Lbs.
Dalmarnock .	B. and W.	62,500	275	700	134
Gennevilliers .	Stirling double-ended	176,000	355	707	129
Barton . . .	B. and W. double-ended	120,000	375	738	133
Proposed double-ended Clayton type		300,000	500-750	..	223

On taking out the total floor-space occupied by large boiler units, it would appear from present practice that, utilizing the types of boilers proposed, with mechanical stoking, the grate-area would be approximately 18 per cent. of the total boiler-house floor-space. That was rather an important point in design, on account of the high capital cost entailed in large boiler-house buildings. The Author was not very definite with regard to the best working-pressure and temperature, suggesting 500 to 750 lbs. per square inch. It would appear, from estimates prepared on the basis of present-day prices, that fairly large high-pressure units would involve excessive capital costs and obsolescence charges. Obsolescence had to be faced: progress was so rapid that it might be necessary to write off some instalment of plant in 10 years, and that had to be added to the capital charges. Considering the thermal-efficiency gains on the heat-cycles used and proposed, it did not seem possible to justify at the moment anything more than ordinary pressures in the region of 420 lbs. per square inch. He was basing that on metallurgical considerations, using a "straight" carbon steel of 0·15 or 0·20 per cent. carbon—a standard product. Researches showed that the strength was seriously affected at the temperature involved, and the pressure indicated gave a temperature in the region of 450° F. in the boiler-drums. It was questionable whether it would pay to exceed these figures; the factor of safety had to be increased out of all proportion to the design. There was no difficulty about the boiler-tubes, as the factor of safety in modern boiler-tubes ran into thousands; and, if the diameters of the pressure parts were reduced, there was no reason why a boiler should not be made for 5,000 lbs. per square inch working-pressure if a customer was prepared to pay for it. Engineers were approaching a type of construction which was a combination of blast-furnace practice and big-gun manufacture. High-pressure drums had to be forged out of the solid, and the cost was very high. It was experimental or pioneer work, for which the ordinary purchaser could not pay. Unless special alloy steels were used, as proposed by Sir Robert Hadfield, there was no commercial ground for using such very high pressures in large power-station plant in the next few years. Mr. Jockel.

Mr. CHARLES ERITH remarked that the Author referred to the use of very large boilers in France, and the double-ended units mentioned could be seen by anyone interested in the subject at the Compagnie Parisienne's station, at St. Ouen, Paris, where fourteen such boilers, each with a Riley stoker of duplex type, burning 10 tons of coal per hour, on a double-ended furnace 30 by 23 feet, were now being used. These fourteen large boilers had replaced a large number of smaller boilers, and the steam-turbine unit was of 30,000 kilowatts, each unit supplied by two such boilers. That example of ordinary practice showed that the large boiler with a capacity of 200,000 lbs. was a commercial article. On the question of thermal efficiency, it was interesting to remember that a very small "Locomobile" boiler, say 100 HP., could be constructed so as to show the thermal efficiency of the very largest unit; but, as had been pointed out, the obsolescence of the Lancashire boiler Mr. Erith.

Mr. Erith. was due to its small unit size. Mechanical handling of coal and ash was only practicable with the relatively large water-tube boiler. He was interested in what Mr. Tresilian had said on the question of pre-heated air, a subject that had attracted a great deal of attention recently. There seemed very little doubt that when air was introduced at a high temperature into a furnace, all sorts of difficulties were met with. One which had not been referred to was the largely increased volume of the pre-heated air, which, with a given grate, must reduce the capacity of the boiler, on account of the reduced weight of air that could pass through the grate. Very little had been heard in the discussion about pulverized coal, which had been referred to several times as the only means of firing really large boilers. There did not seem so far to be any evidence to prove that. In America much experimental work had been done with pulverized coal, but also very large boilers had been constructed for direct combustion with stokers, which in America were almost universally of the retort type. There was no difficulty whatever in fitting a furnace of any size and distributing the required proportion of fuel; and (as Mr. Tresilian had mentioned) the modern development of the travelling-grate stoker was such that it could be built up to any width required. The difference in thermal efficiency was very small. On the question of unit size of boilers, it was interesting to compare the double-ended type with similar single-ended boilers. It was simply a matter of convenience whether two single-ended units or one double-ended unit of the same capacity were used, and they could use the same means of firing; for instance, each pair of single-ended boilers at Edinburgh, at Calcutta, at Shanghai, or at Sydney, used the same two Riley eighteen-retort stokers as fitted to each double-ended boiler at Paris, for identical duty.

Mr. Parsons. Mr. R. H. Parsons remarked that in the last few years the size of turbo-generators had increased from about 1,000 to 50,000 kilowatts, and there ought to be some sort of reasonable ratio between the sizes of boilers and of turbine-units. That being admitted, the average boiler should apparently be a great deal larger than at present; but it was for the advocates of larger boilers to justify their claims on economic grounds. Mr. Patchell had shown a boiler-house about 145 feet high, which was about the height of the Nelson column. Such a structure was costly, and it was questionable whether such greater efficiency was obtained as to justify the construction. Engineers were never told the cost of such huge boiler-houses. Apropos of Mr. Jockel's figures, he had recently given a Table[1] comparing the generation of steam per unit of floor-space,

[1] Minutes of Proceedings Inst. C.E., vol. ccxviii, p. 401.

Mr. Parsons. etc., for seven different stations; but the main consideration was the following. There was a limit to the weight of coal that could be burned economically per square foot of grate-area. For the sake of the argument the actual figure did not matter. That fact constituted a limiting condition, and the cheapest boiler-house for a given output would be that one in which it was possible to cover the greatest part of the whole floor-area with fire. If the whole of it could be covered, it would be possible to produce at least 12½ kilowatts per square foot of floor-area in average practice. He did not think there was any justification in taking only into account the area occupied by the boilers themselves, in considering the effective utilization of floor-space: the gangways had to be considered, and the whole of the boiler-house had to be paid for. Therefore the calculations must be based on the whole floor-area. In dealing with the circulation in various types of boilers, the Author stated that in the Babcock marine type the water came down one header and passed along all the tubes and up the other header. In the United States experiments had been carried out recently with regard to the circulation in such boilers. The tube-caps were bored and fitted with glands through which were passed spindles, and on these spindles were mounted small propellers in the tubes. Revolution-counters were fitted to the exposed ends. By this means a fair relative measure of the circulation-speeds in the different tubes had been obtained. The experiments showed quite distinctly that, when such a boiler was steaming normally, the water only circulated in the manner described by the Author through about one-third of the tube-bank. It passed from the front to the back header in the lower tubes, the steam passing up the header to the drum; but the water returned to the front header by the upper tubes, flowing in the reverse direction to that intended. If anything like that occurred in a simple boiler such as the Babcock marine type, it would be very bold to predict what would happen in more complicated boilers. With regard to the Clayton boiler, was not there something wrong in *Fig. 3* (p. 138)? He understood that boiler had a longitudinal baffle in the front drum which turned the water down and controlled the circulation, but the drawing did not show a baffle, and if none was fitted it was more than doubtful whether the water would circulate as intended. The same remarks applied to the rear drum of *Fig. 6* (p. 142). Captain Sankey had referred to a German high-pressure steam heating-system. He did not know when the German system was first used, but Jacob Perkins was the true inventor, and began to install the same type in this country about 50 years ago. He knew of an installation within ½ mile of the Institution which

Mr. Parsons. had been running all that time, and he believed there were others still at work.

The Author. The AUTHOR, in reply, expressed his thanks for the way in which the Paper had been received, and for the friendly and helpful criticism which had been made. No one knew better than he did that it had limitations; but he was sure the members would agree, on consideration of the observations and criticisms they had heard, that it was quite impossible in one Paper, or in many Papers, to cover a subject so large, so technical, and having so many points of view. Therefore, he had had to choose what were to be his limits for a single Paper, and he thought it would add to clearness if he also limited the ground he attempted to cover in replying to the discussion. Mr. Patchell, in proving that large boilers were an accomplished fact, had described large boiler after large boiler, every one of which had been installed in America. That was interesting from the point of view of British technicians, who wanted to know what was happening abroad; but it was more important to know what was happening in England. The conclusion seemed to be that, whether big boilers were advantageous or not—that, of course, being open to considerable argument—there were none in this country, and, so far as he knew, none were being contemplated. Therefore, if they were desirable, engineers would have to take care that this country was not left behind. It was very necessary in these days, when British engineering was going through the most difficult and troublesome time it had ever experienced, to take care, for commercial reasons, that British practice was in the very front rank. It was not very satisfactory to British engineers to find that in motor-ship development every type of motor-engine fitted to ships bore a foreign name. When it came to large-boiler practice he most sincerely hoped that, if ever this country was called upon to build large boilers, manufacturers would not be content merely to follow what had been done abroad, but would have the necessary technical judgment and experience to develop their own practice and to choose and adopt that which was truly a British expression of what high-class engineering ought to be. Colonel Crompton had pointed out what was really after all the heart of the matter, namely, the bogey of premature obsolescence in connection with electric plant. The only way he could see of preventing premature obsolescence was to look ahead and make sure that the type of plant which was adopted was likely to be somewhat in advance of present-day practice, rather than behind it. This country was committed, as a national policy, to very large electric power-stations. Boilers of large size might not have been required in the past, but they were certainly

The Author. going to be required in the future if they had any merit. Large stations required large plant. If there were no large boilers at work in this country alongside a number of boilers of smaller size, it was impossible to get the comparative data for which Colonel Crompton and others had asked. He emphasized the point that, from the experience already possessed, it was a matter of common knowledge that, where a number of small boilers were replaced by a single larger unit, the economies appeared to be substantial. The question was: what was to be the limit of capacity of the unit? He doubted whether any engineer was in a position to give comparative figures, but that was no reason why the subject should not be explored. There were sufficient prima facie facts to lead to the broad view that large demands required large plant, and the whole tendency was for that large plant to be forthcoming. He ventured to repeat what he had said in the Paper: that, where large plant had to be contemplated, the argument was always put forward with considerable force, that it was a wrong thing to have too many eggs in one basket; but, whilst that consideration imposed necessary care, it did not prevent progress. The generation of electrical energy on a larger scale than ever before was now a national question. He, with others, was most anxious that the large generating-stations which were being contemplated in connection with the bulk supply of electricity should be leading, and not following, examples of what ought to be. Colonel Crompton had also laid stress upon the fact that real success came from close attention to detail. In connection with boiler-design, it would occupy unduly the time of any investigator to attempt to classify the various permutations and combinations of tubes in one form and another which had been devised by designers for many years past. It was difficult, if not impossible, to say that anything in connection with tube arrangements was actually new. He simply pointed out, in connection with that careful attention to detail which Colonel Crompton urged, what seemed to matter in connection with obtaining boilers which would have a higher degree of reliability and a higher degree of duty, so that large boilers could be got into a reasonable space. The advantage of that was that it would enable a boiler-house of large power to be produced at very much less cost and in very much less space than otherwise would be possible. From that point of view alone he doubted the necessity for much of the American practice. Mr. Stromeyer had spoken of "cathedrals" in connection with furnaces, but he was not convinced that anything of that extraordinary character was really required. He concurred with Mr. Stromeyer's view of the Barton boilers, and he did not think the

The Author. development of large boilers should take place by combining two boilers with independent casings: although a common drum was used, to all intents and purposes each unit was composed of two boilers. If the intermediate walls between the boilers were eliminated and the whole boiler was brought into one, there was a large reduction in the wall-area subjected to the furnace temperatures, and that was the direction in which engineers ought to go. He also cordially agreed with Mr. Stromeyer's remarks on radiant heat. In the recent discussion which took place in the Institution with regard to the proposed boiler test-sheets in connection with the Heat-Engines Committee, he had been at some pains to observe that he thought the differentiation which was contemplated in the setting out of the tube-surface exposed to radiant heat, without taking into account other factors, might produce a misleading comparison. Taking the criticisms as a whole, he suggested that in themselves they supplied adequate reasons for the submission of his Paper at this juncture. The difficulty referred to by Colonel Crompton, of premature obsolescence in the plant of central electric generating-stations, up to the present time had arisen from two main causes. The first was failure on the part of those concerned to realize the rapid growth of demand for electrical energy, with the consequence that the units installed had proved to be quite inadequate long before the expiration of their normal life. The second cause was that there had been great technical improvements, both in turbine and in boiler practice, which had justified much earlier supersession of existing plant than would normally be the case. If these lessons of the past were to be taken into account for future guidance, the Author insisted that the adoption of larger boiler-units was inevitable. There was no physical reason why a large boiler-unit should be less reliable than a turbine-unit of similar capacity. On the contrary, as the boiler in itself was not, like the turbine, a delicate piece of finely-fitted mechanism revolving at high speed, it ought to be more reliable than the turbine. One of the Author's chief points was that if proper advantage were taken of modern developments in boiler practice, this position of security in respect of large boilers could be obtained. Turning to the general trend of thought with regard to technical improvement, the turbine-designers had made their position clear. They intended to move along the line of higher pressures and superheat temperature. Hence the Author's contention was that, taking all these things together, the line of boiler development must be for the size of boiler-units to approach more and more nearly to that of turbine-units, whilst pressures and superheats would also advance. Nothing had been said by the various speakers which diminished the force of this contention. On the contrary, Mr. Parsons and Mr. Jockel, who were directly concerned with the operation of generating-station plants, took it as a matter of course that the concentration of a given boiler-power within a much smaller floor-area than was at present the case must mean a substantial reduction in first cost and therefore in capital charges. The attitude of those two speakers should be distinguished from that of the others who had questioned any gain in working efficiency from large boiler-units as against the same aggregate power in a larger number of smaller units. In this latter connection, however, it was to be noted in passing that Mr. Stromeyer admitted a prima facie case for higher efficiency in large units. On the question of reduced capital costs it might be stated that where the conditions of load-demand permitted the employment of large units, to halve the number of boiler-units employed by doubling their capacity would, if the right design of high-duty boiler-unit were adopted, effect a saving of between 20 and 30 per cent. on the total cost of the boiler-house and its equipment. In view of this substantial gain smaller gains in working efficiency were of less moment, but they were undoubtedly in the right direction. The Author had considered it outside the scope of the Paper to introduce references to the special types of boilers mentioned by Mr. Stromeyer and Captain Sankey. Nor had it been his purpose to give the Paper an historical character by mentioning the individual contributions which had been made from time to time to progress in boiler design. His object had been to draw attention to what seemed to him to be safe basic lines along which future development in boiler-design could with much advantage proceed. He pleaded for initiative and enterprise in the evolution of truly British practice which, while taking full account of what was being done in other countries, would lead them all in efficiency and general excellence. The Author.

Correspondence.

Mr. Wm. Burnside remarked that the Paper was valuable alike for the Author's statement of the present position, his discussion of water-circulation and higher rate of steaming, his deductions, and his forecast. Mr. Burnside agreed in the main with his conclusion that further progress would lie in the adoption of large units fired by powdered fuel. He was not sure that the header sectional type was preferable to the tube-in-drum type. For one reason, the Mr. Burnside.