general principles, but in which one combustion chamber supplies a number of small boiler tubes. This boiler is shown in Fig. 7. It comprises a boiler shell provided with packed tubes of 3-in. bore and a feed-water heater furnished with similar tubes. The author is informed that good results have also been obtained from this boiler, and it would appear that the plan of construction involved may afford a useful alternative.

### Solid Fuel.

The author has discussed in this paper the use of gaseous fuel with the Bonecourt boiler, and has also shown how such boilers may be fired with liquid fuel. There remains therefore only to apply the system if possible to solid fuel —the largest field of all. This field of investigation has already been attacked, and although a Bonecourt boiler fired direct with solid fuel is not yet a *fait accompli*, the attempts which have so far been made in this direction afford hope of a very useful result being obtained at no distant date. The experiments which have already been carried out have produced remarkable results: in a small apparatus fired with solid fuel, evaporating 334 lb. of water per hour from and at 212° F., complete combustion of the fuel has been obtained, although the amount of air supplied for the combustion was practically no more than is required by theory, as is shown by the following analysis of the combustion products:—

| | |
|---|---|
| Carbon dioxide ... ... | 19·1 per cent |
| Oxygen ... ... ... ... | 1·4 ,, |
| Carbon monoxide ... ... | 0·0 ,, |
| Nitrogen ... ... ... | 79·5 ,, |
| | 100·0 ,, |

The evaporation amounted to 17·8 lb. of water from and at 212° F. per square foot of heating surface per hour. Such a result is remarkable from the point of view of both a combustion phenomenon and the evaporation performance. This result was communicated by the Bonecourt Company to their German allies, the Berlin Anhaltische Maschinenbau Aktiengesellschaft, who expressed themselves sufficiently impressed with the results to undertake immediately the further development. They have constructed a coal-fired Bonecourt boiler and are about to put it under test. This first construction is naturally of a tentative nature, but it is hoped that it will pave the way for a considerable enlargement of the field of surface combustion as applied to steam generation.

## Discussion.

Mr. Jockel. Mr. L. M. Jockel: Papers dealing with boiler work are very welcome as it seems that at the present time further improvements in the efficiency of steam plant are more necessary in the boiler house than in the engine-room, especially when one considers that in many up-to-date power stations something like 50 to 70 per cent of the works costs is accounted for in the boiler house. On page 724 the author states that a draught of about 15 in. (water gauge) is required, and that this can be produced either by induction or by forcing. If the latter method is adopted it appears that two fans will be necessary, one for the gas and one for the air; in all probability, however, the induced-draught arrangement will prove in practice the more satisfactory and efficient of the two methods. To produce this pressure difference an appreciable amount of power will be required—possibly some 3 to 4 per cent of the power developed by the boiler—and this fact must be considered when comparing boiler efficiencies. In land practice with water-tube boilers working on induced draught the power required for driving the fan seldom exceeds about 1 per cent of the boiler power. In connection with the driving of the fan the lay-out shown on page 727 represents a duplicate fan plant arranged for both electrical and steam-turbine drive. The latter method might prove very economical, as the heat in the exhaust steam could be utilized for heating the feed water previous to its entering the gas-fired heater or economizer. On the other hand this arrangement might not prove so reliable, as during heavy loads the draught would be largely dependent on the boiler pressure. At such times in a power station one naturally wishes to speed up the auxiliary plant in order to get over any difficulty such as low steam pressure as quickly as possible. The evaporative power of the boiler would appear to be some 3 to 4 times greater than in the case of an ordinary water-tube boiler, and it would be interesting to know whether priming does not occur when working at such high rates— particularly in view of the fact that nowadays such Mr. Jockel. excellent results of boiler tests are published from time to time. As high superheats are now of great importance it would be of interest if the author could give details of suitable superheaters, as no mention seems to have been made of their application to this type of boiler. The compactness of the boiler should be a valuable feature in many cases, the lay-out shown on page 727 illustrating this point. An ordinary water-tube boiler appears to require about 18 sq. ft. of floor space per 1,000 lb. of water evaporated per hour, whereas a Bonecourt boiler would only require say 14 or 15 sq. ft. of space for the same duty. On page 728 the author mentions in connection with an oil-fired boiler that steam at 110 lb. pressure can be raised from cold water in 50 minutes. In view of expansion troubles this would hardly seem to be good practice with a shell-type boiler, particularly with a multitubular design having a large ratio of diameter to length and flat stayed surfaces. From practical experience with multitubular boilers of the shell type I have always found that there is a certain amount of "dead" water present unless some efficient circulating device is utilized; but perhaps the author gets over this difficulty by placing the fire tubes very low down in the boiler. The maintenance of boilers is an important factor, and it would be interesting if the author in his reply could give some figures in regard to that item, as I understand that some Bonecourt boilers have now been working under practical conditions for over a year. In view of the high evaporative rating, it would seem that scaling would be frequently required unless the feed water is remarkably pure, while unless the gas is carefully cleaned the fire tubes and granules will tend to get clogged. The latter difficulty might possibly be overcome by periodically refluxing the tubes.

Mr. W. M. Selvey: The Bonecourt system will be of Mr. Selvey. great use to the community when it has found its right

Mr. Selvey. sphere. A suggestion rather than a positive statement is made on page 727 in the paragraph which states that Bonecourt boilers have been used as a link in the system of generating power from coal by means of ammonia-recovery producers. I think that this is not borne out by the circumstances quoted. All that I see in it is a boiler installation for supplying the Mond type of producers with the large quantity of steam which on the one hand is so necessary if a large yield of ammonia is to be obtained, and on the other hand is so detrimental to the heat efficiency. I have no wish here to open up this old controversy; those interested can refer to the discussion on Mr. Humphrey's paper before the Institution of Mechanical Engineers,* but I feel compelled to point out that if Mr. McCourt wishes us seriously to consider this boiler as a link in the chain for obtaining power from coal via a producer, a steam boiler, and a steam turbine, rather than by producer plant and a gas engine, then I must certainly dissent from the balance sheet for the efficiency of his boiler. It is the old question of the producer efficiency being taken on the "gross" or "higher value" of the gas, and the gas-engine efficiency on the "net" or "lower value." I have come to the conclusion that with a Mond type of plant, with a boiler of the highest efficiency that I have personally tested, and with steam supplied to the producer from a mixed-pressure turbine, the amount of coal burnt in the producer-boiler system is 1·43 times that of the same boiler with a modern chain grate. Now this coal-fired boiler had an efficiency of over 85 per cent reckoned on the "higher value," and on the "lower value" it would have had an efficiency of over 88 per cent, so that accepting the author's figure of 95 per cent for this boiler, and deducting 2 per cent for "extra" fan power, we are only 5 per cent better off and the ratio is only reduced from 1·43 to 1·36. Now this chain-grate boiler which I have in mind would burn even the poorest class of coal, whereas the producer to go with this boiler would require a coal not only carefully selected but containing a high percentage of nitrogen. I look for the solution of the problem therefore rather on the lines of the combined coke-oven-waste-heat power station in which this boiler may legitimately find a field. In such cases land is generally cheap and the size of each unit is small. The present boiler is a return to the fire-tube type, which has generally been limited to an evaporation of about 15,000 lb. per hour, whereas our modern large power stations are now being fitted with Babcock and Stirling boilers which can easily evaporate 40,000 lb. of water per hour—indeed, in the United States a number of boilers of the Stirling type have evaporated 100,000 lb. per hour. The Bonecourt boiler, to give an efficiency of 95 per cent, has an economizer that reduces the temperature of the outlet gases almost to the condensation point of the water vapour carried by them. The effect of any such condensation will be known to those who have occasionally run economizers with feed water below 90° F.; a solution of sulphuric acid is produced which plays havoc with the metal-work. I expect that the author has already heard of this. Corrosion would also occur in the suction fan if it were placed in the outlet gases; but I think that this could be remedied by placing the fan between the boiler and the economizer. It may be news to some members that economizers of the pipe type have already given outlet temperatures lower than those mentioned in the paper, and with a fan power of only 2 in. (water gauge) instead of the 15 in. to 30 in. quoted. The extra power required for this draught as compared with the usual type of fan has not been debited against the 95 per cent efficiency claimed. The outlet temperature from the boiler itself is quite a normal figure for a water-tube boiler, and there is no particular item from the combustion to the temperature of the outlet gases that could not be produced by other means at present available. The fan power is quite a considerable item. The power required for 1,000 cub. ft. of air at a pressure of 20 in. (water gauge) is 3·04 h.p. Assuming reasonable efficiencies, I find that the power required for the fan for an electrical drive is equivalent to 2·9 per cent of the steam generated—Professor Bone in one of his papers allows 4 per cent. If the steam is provided by a high-pressure turbine and its exhaust is used for feed-water heating, the consumption will not be better than double this figure, which means practically 6 per cent of the total steam. This is nearly as much as the feed water can take up under ordinary conditions, having already the steam from the feed pump, and is enough to prevent the final temperature of the gases from approaching 200° F. The electrical drive is of course dependent on electrical power always being available before the boilers are started up. There are several other points which might be put forward, such as the arrangements for meeting rapidly varying loads and the adjustment of the ratio of the gas and air, on which the author could give us welcome information. I should like to close my remarks with a note of appreciation. The author has produced a boiler situation similar to that in connection with gas engines, in which the small unit is as efficient as the large. He has put forward an exceedingly clever flash boiler on a much larger scale than hitherto, and has provided a means of prolonging the life of many small private plants which are using steam as an alternative to electric power supply from a large company.

Mr. Christianson. Mr. W. A. CHRISTIANSON: The author refers to the possibility of using boilers of the water-tube type worked on the Bonecourt gas combustion system, but he has shown no actual designs. The Bonecourt system of combustion is excellent, and had it been arranged so that it could be adapted to boilers of existing types more progress might have been made. So far, development appears to be confined to boilers of the fire-tube type, and the largest size made up to the present is only of 11,000 lb. per hour evaporative capacity. There is therefore not sufficient inducement for power users to discard their existing boilers for Bonecourt boilers. No reference has been made to the use of blast-furnace gas on the Bonecourt system, and blast-furnace gas is undoubtedly a most important field of gas firing. It seems to me that it would be necessary to clean the gas first, as otherwise the boiler tubes and granules would become badly choked after a short time. Cleaning of blast-furnace gas has made considerable progress in Germany, but not so much in this country, and therefore I think that the Bonecourt system will not be adopted in this sphere. The boilers described by the author supply saturated steam only. For present-

* H. A. HUMPHREY. Power-gas and large gas-engines for central stations. *Institution of Mechanical Engineers, Proceedings*, p. 41, 1901.

Mr. Christianson. day power installations it is essential to have superheated steam, and it would seem to be a matter of some difficulty to arrange for this with a Bonecourt boiler, as the exit flue-gas temperature at the back of the boiler portion is too low for superheating purposes. The high efficiency claimed appears to be to a great extent due to the feed-water section. Reference to one of the author's tests shows the exit temperature from the boiler section to be 608° F., while of the total efficiency of 92·5 per cent, 83·7 per cent is due to the boiler and 8·8 per cent to the heater. The figures corresponding to the boiler are by no means exceptional, and I am of opinion that equally good results are being obtained from coke-oven gas-fired boilers of ordinary make where similar care is taken in the working of the boiler as has been done in these Bonecourt boiler tests. Blast-furnace gas-fired boilers are notoriously inefficient, but the same cannot be said of coke-oven gas-fired boilers. Although figures are not generally published, I think that with reasonable care efficiencies of 85 per cent would be obtained. The high efficiency of the Bonecourt system is further due to the surface combustion with its resulting minimum amount of excess air, and the impinging effect caused by the granules in the tubes. The surface combustion can be imitated in a simple fashion by properly arranged chequered brickwork in the furnace chamber of any water-tube boiler, and as in boilers of this class the impinging principle on the tubes is already fairly well carried out, I am hopeful that such a combination would be equal in practical efficiency to the Bonecourt system—especially so in a boiler of the Stirling type where the back section of tubes is practically an economizer section. The impinging or retardation principle in fire tubes has already been appreciated, as evidenced by occasional attempts to fit retarders to marine boiler tubes. These have generally had to be discarded owing to choking. Coal-fired boilers have generally lower efficiencies than coke-oven gas-fired boilers, and this should be borne in mind when considering the high efficiency claimed for the Bonecourt system. For the present I think that the Bonecourt boiler is suitable only for small plants. Incidental advantages of the system are that the nozzle control allows each burner and tube to be worked at its maximum efficiency throughout a wide range of power, while in case of low water it is possible to shut off the top burners and so prevent damage. A disadvantage is that the boiler is not readily adapted for changing over to coal firing, which is sometimes necessary. With the multiplicity of burners used on gas-fired boilers, there is the possibility that the mixture in each may vary, resulting in a lower efficiency; but this difficulty is satisfactorily overcome in the oil-fired boiler shown in Fig. 7, which has a preliminary mixing chamber. On previous occasions the diaphragm principle of firing gas on the Bonecourt system has been put forward, and I thought that this might have been adapted so that it could be used on existing types of water-tube boilers. Perhaps the author will tell us why no such development has taken place. About twelve months ago I inspected the boiler at Skinningrove and was informed that it was giving very satisfactory results. With regard to the author's statement that the evaporation is proportional to the square root of the difference of pressure between the opposite ends of the boiler tube, I have found that a similar law applies to an ordinary chain-grate coal fire. Perhaps the author will be able to enlighten us further on several of the points referred to—more especially in regard to adapting his principle to existing makes of boilers for large powers, and in regard to comparisons with existing methods.

Mr. McCourt. Mr. C. D. McCourt (*in reply*): The following points have been touched upon in the discussion, and I propose to consider them in the order in which they arose, namely:—(1) Power consumption for fan driving; (2) the possibility of priming due to the high rates of evaporation obtained; (3) the provision of superheaters; (4) the possibility of straining a Bonecourt boiler by too rapid starting from cold; (5) the cost of maintenance of the boilers; (6) the necessity for removing scale deposited on the tubes; (7) the possibility of the boiler tubes becoming clogged up internally by dust deposited from gaseous fuel; (8) the cost of generating steam by means of ammonia-recovery producer gas; (9) corrosion of the feed-water heater and fan due to condensation; (10) the suitability of the system for meeting rapidly varying loads; (11) the employment of blast-furnace gas.

Turning first to the question of power consumption for fan driving, it should be remembered that the figures which have been recorded up to the present have been measurements upon fans not expressly constructed to give good efficiency for the duty required. In the case of large installations of Bonecourt boilers it would be possible to use standard fans having efficiencies ranging between 70 and 80 per cent for a considerable variation in load. The results of carefully made tests on exhausters of large capacity, constructed by the De Laval Company of Sweden, show that for large boiler installations the percentage of power necessary for driving the exhausters may be reduced far below the figures mentioned in the discussion; in fact, taking the fan tested, over a considerable variation in load the fan power would be below 2 per cent of the boiler output. With regard to the power required for the fan, it should be recollected that centrifugal fans possess the useful property of giving when driven at a constant speed almost constant suction for very great variations in load.

Careful measurements have been made of the wetness of the steam produced from Bonecourt boilers evaporating at high rates, and in every case the steam has been found to be technically dry. The excellence of the circulation induced by the steep evaporation gradient along the tubes is probably partly responsible for the absence of priming, but a more important factor in this connection is that the boiler in question is a fire-tube boiler and not a water-tube boiler. If a water-tube boiler were to evaporate at the high rates obtaining in a Bonecourt boiler, the steam formed in the tubes might be expected to shoot water into the steam spaces and cause serious priming. Water tubes are known to act spasmodically in the generation of steam, and can be observed acting much in the manner of popguns if a suitable model be constructed and operated.

Superheaters can be readily provided in Bonecourt boilers, the boiler tubes being chosen on the short side so as to obtain the necessary temperature of the combustion products, the superheater being located between the boiler and the feed-water heater, and the feed-water heater having to do a little more work by reason of the increased temperature of the entering gases. If a high degree of superheat be required, the boiler can be designed of a short

Mr. McCourt.

length and furnished with an equal number of combustion tubes and return tubes, the superheater being located at the end of the boiler shell and therefore being subject to a surrounding gaseous medium at a temperature of 600 to 900° C.

It has been suggested that if boilers of high steaming power such as the Bonecourt boiler are started quickly, straining will take place owing to unequal heating of the shell. This has not been found to occur, and immunity in this respect is attributable to the vigour of the circulation produced by the steep evaporation gradient along the tubes. The vigorous circulation prevents the formation of "dead" water at the bottom of the boiler, and hence every part of the shell increases in temperature at a nearly uniform rate however quickly steam may be raised starting from cold.

With regard to cost of maintenance of the boilers, the absence of heated joints and the restriction of the heat transmission area to the tube surfaces must make for a low cost. Bonecourt boilers have not as yet been sufficiently long in use commercially to afford data on this head, but they have at all events been sufficiently long in use to show that during two years' operation no necessity for repairs of any kind has been encountered either in the straining of the shell or the burning or impoverishment of the boiler tubes or tube joints.

No trouble has yet arisen with regard to scale formation. The scale formed on the tubes is shed off as soon as it reaches a thickness of about a millimetre. On opening the Bonecourt boiler at Skinningrove after it had been running for some months, no scale thicker than a millimetre was found on the tubes, but in the bottom of the boiler shell was found an accumulation of detached scale, which had evidently been dropped from the tubes after attaining a certain thickness.

Experiments have been made with gases heavily laden with dust, and it is found that very little dust settles in the boiler tubes. The speed of the gases passing through the tubes effectually prevents serious deposition of dust, any dust tending to collect being at once moved on by the violence of the blast.

With regard to the comparison between the relative advantages of Bonecourt boilers and gas engines for the development of power from ammonia-recovery producer gas, it is thought that a discussion of this subject, involving as it does a full consideration of a great diversity of points, cannot advantageously be entered upon here. It will be evident, however, that the simplicity and low first cost of large turbine sets of say 10,000 to 12,000 kw. offer compensating advantages to set against the lower fuel consumption of gas engines limited to sets of about 2,000 kw.

Mr. McCourt.

It has been suggested that the gases in passing through the feed-water heater of a Bonecourt boiler are cooled down to the point at which condensation may take place, and that if this occurs it will be found to cause serious corrosion. This can be obviated by causing part of the hot feed water to circulate back again to the inlet of the feed-water heater, thus preventing such undue cooling of the flue gases as would produce condensation and consequent corrosion.

To meet variations in load, any number of tubes can at a moment's notice be turned off, and when required again can as quickly be lighted up. To do this it is only necessary to manipulate a damper and the necessary valves. By this means any desired output of steam from 1 per cent to 100 per cent of the maximum output can be obtained at any time. A more elastic control of steam generation can scarcely be conceived, the response of the boiler to alterations in the supply of gas being immediate.

Coming finally to the firing of Bonecourt boilers with blast-furnace gas, two large boilers each evaporating 15,000 lb. of water per hour are about to be constructed by a large firm in Belgium for their power station. Preliminary experiments have been carried out at their works, the gas employed possessing a calorific value of 105 B.Th.U.'s per cubic foot, and yielding an evaporation of 20·5 lb. of water from and at 212° F. per square foot of heating surface per hour. The flue gases analysed :—

| | |
|---|---|
| Carbon dioxide ... ... | 16·4 per cent |
| Oxygen ... ... ... | 2·6 ,, |
| Carbon monoxide ... ... | 0·0 ,, |
| Nitrogen ... ... ... | 81·0 ,, |
| | 100·0 |

This composition shows that the combustion is complete even when the amount of excess air employed is almost negligible.