Published in this Issue,

By kind Permission of The American Society of Mechanical Engineers the following Paper on

The Clinkering of Coal,

By Mr. LIONEL S. MARKS (Member),

There is a growing feeling that the matter of clinkering ought to be taken care of when making contracts for coal and that specifications ought to include the melting temperature of the ash as indicating the clinkering characteristics of the coal.

The useful items in modern specifications for coal are the heat of combustion of the coal and its water and ash content. The latter permit calculation of the cost of handling inert matter when firing the coal and when disposing of the ashpit refuse. The volatile content of coal has an indirect interest in indicating its general nature but does not give any definite information about burning qualities. The important things about which specifications give no information are (*a*) as to the burning qualities of the coal (free burning or dead, caking or non-caking, etc.) and (*b*) the clinkering characteristics of the ash.

Before the subject of clinkering can be put upon a satisfactory basis, two kinds of measurement are necessary; (*a*) the determination of the extent to which the clinkering of a given coal is objectionable in actual use, and (*b*) the determination by a laboratory test of some characteristic of the ash which indicates the objectionableness of the clinkering. Some clinkers give very little trouble and are not particularly objectionable even when present in large amount. This is especially true of such clinkers as are non-adherent, easily broken up and easily removed. On the other hand, a small quantity of clinker which forms a pasty mass with the surrounding coal, or which runs on to the grate and freezes there as a strongly adherent but thin sheet, gives a very great deal of trouble and diminishes both the capacity and efficiency of a boiler considerably.

It is probable that the only reliable basis at present for determining the "objectionableness" of the clinker, is the judgment of fire-room observers. The writer has attempted to get a quantitative measurement by sifting the ashpit refuse into a number of selected sizes. In tests made with a Murphy stoker equipped with the usual clinker-breaker, the coals which gave most trouble were found to have the lowest percentage of smallest size clinker (less than 1 in.), and the highest percentage of the largest size clinker (greater than 2 in.). The differences between the percentages of the different sizes for good and poor coals is but small, so that the method cannot be relied on, but these observations have been used to confirm the judgment of the fire-room observers.

The only kind of laboratory test on coal ash which would seem to be of any real value is one in which the ash is subjected to such temperature as will cause it to melt either wholly or in part. A number of attempts have been made to determine the melting temperature of an ash from its chemical analysis, but none of these attempts has been satisfactory, nor does it seem probable that this method will ever be available in view of the great complexity of the chemical constitution of coal ash.

That valuable indications may be obtained from a knowledge of the iron and sulphur content of the coal or of its ash, is suggested by some recent tests of Palmenburg[1] which, as pointed out by Bergwyn,[2] appear to show the following results:—

(*a*) An ash containing less than 10 per cent. of iron oxide (Fe_2O_3) does not fuse at a temperature below 2550 deg. fahr.; an ash containing more than 20 per cent. does not fuse at a temperature above 2550 deg. fahr.; for an ash containing between 10 and 20 per cent. the fusing temperature varies widely.

(*b*) A coal containing less than 1 per cent. of sulphur does not fuse at a temperature below 2550 deg. fahr.; a coal containing more than 2 per cent. does not fuse at a temperature above 2550 deg. fahr.; for a coal containing between 1 and 2 per cent. the fusing temperature varies widely.

(*c*) A coal containing less than 3 per cent. of iron oxide plus sulphur does not fuse below 2550 deg. fahr.; and a coal containing more than 3 per cent. does not fuse above 2550 deg. fahr.

The determination of melting temperatures of coal ash is attended with many difficulties, the most important of which is in the definition of the melting temperature. When a coal ash is heated slowly, that one of its constituents which is the most fusible will be the first to melt. Its effect upon the rest of the ash will depend upon three factors: (*a*) the amount of that con-

1. Journal of Industrial and Engineering Chemistry, April, 1914.
2. Journal of Industrial and Engineering Chemistry, August, 1914.

stituent; (*b*) its viscosity when melted; and (*c*) its chemical reaction on the remaining constituents. If there is much of this constituent the ash will become fluid to an extent which depends upon its viscosity. If the molten part is small in amount but very fluid, it may separate from the rest. With certain constituents, a eutectic may be formed whose melting temperature has but little relation to the melting temperatures of the constituents.

The best method of determining the extent to which melting has gone on at any given temperature, is probably that which has been used so successfully by the Geophysical Laboratory at Washington. In this method a small mass of the ash is kept at the desired temperature for a time sufficient to insure that the melting corresponding to that temperature is complete. The melt is then quenched and a thin section of it is examined under the microscope. This method, however, may not be the most valuable for the determination of the clinkering characteristics of an ash.

There is another factor of great importance in connection with the behaviour of molten coal ash, namely, its viscosity, which a satisfactory laboratory test for clinkering should indicate as well as melting temperature. The only method which has been used to any extent for this purpose, is really an imperfect method of determining the temperature at which the material has a standard viscosity. This is accomplished by heating the material in the form of a Seger cone of standard dimensions, at a standard rate, until it has bent to some standardised final form. The cone has usually been set up vertically. The rate of rise of temperature is usually taken as 2 deg. cent. (or 4 deg. fahr.) per minute, and the melting temperature is taken as that at which the tip of the cone touches the base. This method, it will be observed, does not really give a standard viscosity unless the time from the beginning of bending is the same in all cases. It should be noted also that the temperature of the cone increases as the bending goes on.

In tests by the writer with a standard rate of heating of 2 deg. cent. per minute, the time taken for the cone to bend to its final position from the beginning of bending, has varied from 10 to 80 minutes; the final viscosities in these two cases are obviously very different. It should be noted that even if this method gave standard viscosities, it would not necessarily give information of any value on clinkering. If it were true that all clinkers became troublesome when they reached a certain lower limit of viscosity, and if that particular viscosity were chosen as the standard, one might expect a close relation between laboratory and fire-room results. It has not, however, been shown that there is a lower limit of viscosity of the ash which cannot be exceeded without trouble from clinker, and moreover, in ashes whose most fusible constituents are very fluid the Seger cone method fails as indicated above.

Notwithstanding these inherent defects, the Seger cone method appears to merit further investigation, but an important modification in its use seems to be advisable. In the standard method the cones are placed vertically. This gives satisfactory results with the original Seger cones with many fire clays, but is often unsatisfactory with more complex mixtures. If the more fusible constituents are very fluid they run down to the base of the cone and may leave the apex apparently unchanged in a vertical or slightly inclined position until it disappears; that is, the cone never assumes the standard final shape. Furthermore, even cones which behave in the normal way may be difficult to observe since their direction of bending is not readily predictable or controllable without preliminary inclining or nicking. Mr. J. P. Sparrow of the New York Edison Company has suggested placing the cones horizontally with the apex projecting over the side of the support. This method has been adopted by the writer as being more sensitive than the usual method and as giving indications which can be duplicated more accurately and are therefore more reliable. The temperatures noted in this method of testing are at the beginning of bending and when the apex of the cone points vertically downward.

The Seger cone method with the cone placed either vertically or horizontally, is used by a number of observers, but with an enormous diversity of the results obtained in different laboratories. This diversity results from differences in methods of testing, from differences in the definition of melting temperature, and also from the difficulties surrounding accurate pyrometric work. The writer has endeavoured to ascertain the influence of the various factors which may affect the apparent melting temperature. The more important factors are (*a*) nature of the surrounding atmosphere; (*b*) size of the cone; (*c*) position of the cone; (*d*) nature of the binder; (*e*) rate of heating; (*f*) location of the cone in the furnace; and (*g*) method of support of the cone.

TABLE I. INFLUENCE OF POSITION OF CONE ON MELTING TEMPERATURE.

Date.	Melting Temperature Deg. Cent.		Difference Deg. Cent.
	Vertical Cone.	Horizontal Cone.	
Feb. 3	1430	1395	35
4	1410	1400	10
5	1410	1400	10
6	1390	1380	10
10	1380	1370	10
13	1440	1395	45
Mar. 3	1440	1420	20
5	1365	1370	5
11	1400	1380	20
13	1445	1395	50
24	1470	1450	20
Seger No. 12 (full size)	1350	1300	50
Seger No. 16 (small size) ..	1450	1420	30

(*a*) *Nature of Surrounding Atmosphere.*—Many of the writer's earlier tests were made with a Hoskins carbon resistance furnace in which the atmosphere is necessarily reducing and in which CO is always present. Preliminary tests on Seger cones gave results which agreed very closely with the readings of a Fery optical pyrometer. The melting temperature of the standard Seger cones was found to be unaffected by the nature of the surrounding atmosphere. With ash cones, however, it was found that the fusing temperatures, as observed in the Hoskins furnace, were in all cases much higher than those obtained in a Meker furnace in which an oxidizing atmosphere was maintained. The temperature in the Meker furnace was read by a Le Chatelier pyrometer which showed close agreement both with the Fery pyrometer and with the indications of Seger cones. The cones were all vertical, and the temperature differences ranged from 120 deg. to 255 deg. cent. (260 deg. to 459 deg. fahr.). It should be noted also that even the order of fusibility was changed in some cases when the atmosphere is changed, and that the lower the fusing temperature in an oxidizing atmosphere the greater is the increase in fusing temperature when changing to a reducing atmosphere. It is of prime importance that the cone should be surrounded by an oxidizing atmosphere.

(*b*) *Size of Cone.*—The size of cone has an influence which is different for different materials. With Seger cones the difference is negligible. For example, a No. 16 Seger cone (17 mm base, 70 mm high) placed horizontally, has a melting temperature (initial and final bending) of 1355 to 1410 deg. cent.; when molded into the standard size of Seger cones of higher fusing temperature (8 mm base, 30 mm high), the result is 1355 to 1420 deg. cent. The size of cone adopted in the writer's tests was 11 mm base and 52 mm high. The ash of March 24 tested horizontally in a cone of this size gave melting temperature 1425 to 1450 deg. cent.; in a 13 mm base, 57 mm high cone, the temperature was 1400 to 1430 deg. cent. As is to be expected, the larger cones show a lower melting temperature but the difference is not great.

(*c*) *Position of Cone.*—The melting temperature (complete bending) of a horizontal cone is always less than for a vertical cone, as shown by Table 1. The difference varies considerably and is less with the more fluid melts. The cones of March 5 or February 10 showed a particularly fluid melt.

(*d*) *Nature of Binder.*—The ash is usually mixed with a 10 per cent. solution of dextrin before molding into cones. It was found, however, that water alone was satisfactory if the cones are not dried much before putting in the furnace. The effect of adding dextrin is generally negligible, but sometimes it increases the apparent fusing temperature (complete bending) by as much as 10 deg. cent.

(*e*) *The Rate of Heating Cones* has a marked effect on the apparent fusing temperature. Any increase in the rate results in increased lag of the pyrometer (Le Chatelier type with porcelain tube), and causes an apparent decrease in the melting temperature. Tests on the ash for February 4 and February 6 showed melting temperatures (complete bending) which were 40 deg. and 35 deg. cent. respectively lower, with 6 deg. cent increase per minute, than with 2 deg. cent. increase per minute.

(*f*) *The Location of the Cone* in the furnace is important; it should be as close to the pyrometric element as possible. The temperature at the front of a No. 29 Meker furnace was found to be about 20 deg. cent. lower than that in the middle of the muffle. An additional door plate reduced this difference.

(*g*) *The Cone must be supported* on material which is unaffected by the highest temperature reached and which does not react chemically on the ash cones. Plates of fused quartz have proved very satisfactory in the writer's tests. They have to be supported in such a way as to permit circulation of the gases below them so that they shall have the same temperature as the rest of the muffle.

Another point of importance is the complete incineration of the ash before it is made into a cone. An appreciable amount of carbon remaining unburned tends to increase the apparent fusing temperature.

The arrangement of apparatus finally used in the writer's tests is shown in Fig. 2. Holes were made in the back of the furnace for the insertion of the pyrometer, and in front for ob-

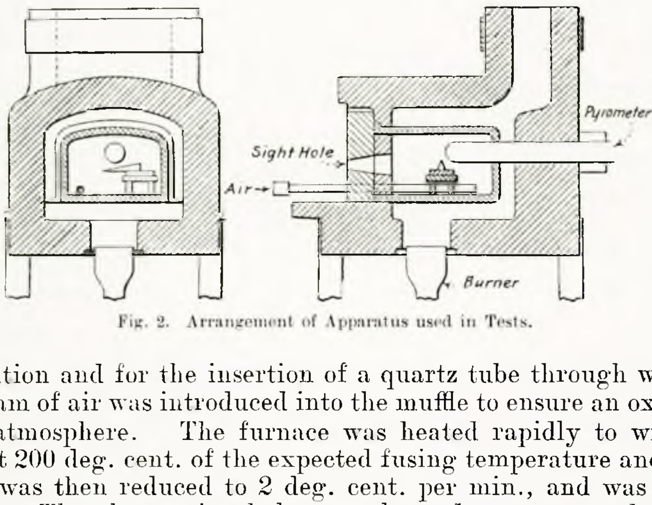


Fig. 2. Arrangement of Apparatus used in Tests.

servation and for the insertion of a quartz tube through which a steam of air was introduced into the muffle to ensure an oxidizing atmosphere. The furnace was heated rapidly to within about 200 deg. cent. of the expected fusing temperature and the rate was then reduced to 2 deg. cent. per min., and was kept there. The observation hole was plugged up except when in use. Observations were made through very dark blue glass at $2\frac{1}{2}$ min. intervals. The horizontal cones were supported only so far as was necessary for balance.

In order to find out whether fusing temperatures as determined by the method outlined above, have any relation to the amount of clinker trouble experienced in burning the coal, a series of tests was carried out on a boiler equipped with a Murphy stoker at the L Street plant of the Edison Electric Illuminating Company of Boston. Fourteen tests were made, each of 24 hours duration, with 10 different coals; five of the tests were made with one coal, and one test with each of the nine remaining coals. Table 2 gives the results of tests of the ash and a statement of the extent of the clinkering for each of these tests.

It will be seen that there is a general relation between the two but that it is not definite enough to be of much practical use. The coals giving the three lowest fusing temperatures (February 10, March 5, April 8) are also those giving the maximum clinker trouble. Those ashes with a final fusing temperature of 1400 deg. cent. (2552 deg. fahr.) or higher, gave little trouble, but the ash of February 6, which melted at 1380 deg. cent. (2516 deg. fahr.) gave little trouble, while those of February 13 and March 13, which melted at 1395 deg. cent. (2543 deg. fahr.) gave much trouble. The most troublesome clinkers (February 10, March 5 and April 8) had final melting temperatures of 1370 to 1375 deg. cent. (2498 to 2507 deg. fahr.) which is practically the same as the temperature for the good coal of February 6. It would appear then, that the final melting temperature cannot be taken as a criterion in the range from 1380 to 1400 deg. cent. (2516 to 2552 deg. fahr.) and the inference is that the uncertain region extends over a still wider temperature range. It is probably true that final fusing temperatures below 1350 deg. cent. (2462 deg. fahr.) show a coal which would give clinker trouble under the conditions of the L Street Station, and that temperatures above 1420 deg. cent. (2588 deg. fahr.) indicate a coal comparatively free from such trouble, but further investigation would be necessary to establish that fact. The important thing, however, from the point of view of coal specifications, is that the tests of the ash of February 3, 4, 5 and 6, when the regular station coal was used which gave a minimum of clinker trouble, yield results which fall in the doubtful region and would therefore be rejected in coal specifications based on fusing temperatures alone.

Additional indications of the liability to clinker trouble may be obtained from the range of temperature during bending and from the appearance of the bent cone. The cones of the ash which gave most trouble had a very fluid constituent which ran down to the tip of the cone and also upon the supporting plate and gave the appearance shown in Fig 3 ; those giving least trouble were as in Fig. 4. It would appear that the most fusible constituents will separate from the rest of the cone when it is very fluid, leaving a skeleton which does not bend until its own fusing temperature is reached; that is, with the kind of ash which gives most trouble, the Seger cone method fails as a result of the separation of the more fusible from the less fusible constituents.

Fig. 3. Fused Cone with Very Fluid Constituent.

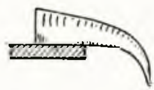


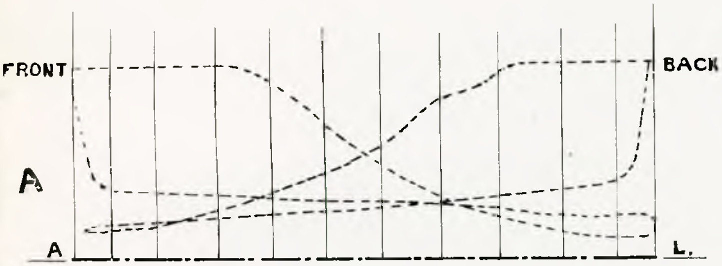
Fig. 4. Normal Fused Cone.

It is possible to accept the appearance of the bent cone as a a partial indication of the clinkering behaviour, and it may be possible to predict the behaviour of an ash from that indication combined with the fusing temperature. The range of temperature during bending may also possibly be used. The range varies from 15 deg. to 55 deg. cent. in the tests given in Table 1; in other tests by the writer it has amounted to as much as 140 deg. cent. There seems to be a very close relation between this range

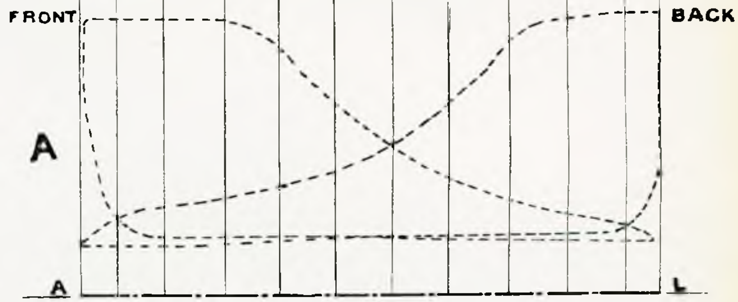
TABLE II. MELTING TEMPERATURE OF ASH AND FIRE-ROOM RECORD OF CLINKERING.

Date.	Melting Temperatures Deg. Cent. (Fahr.)		Amount and Character of Clinker.
	Initial and Final Bending.	Range.	
Feb. 3	1350-1395 (2462-2543)	45 (81)	Light
4	1360-1400 (2480-2552)	40 (72)	Light
5	1360-1400 (2480-2552)	40 (72)	Light
6	1340-1380 (2444-2516)	40 (72)	Light
10	1360-1375 (2480-2507)	15 (27)	Hard, excessive; 50 per cent of grate
13	1350-1395 (2462-2543)	45 (81)	Excessive to moderate; large clinker
Mar. 3	1370-1420 (2498-2588)	50 (90)	Not much, but very hard and isolated
5	1350-1370 (2462-2498)	20 (36)	Excessive; 75 per cent of grate
11	1355-1380 (2471-2516)	25 (45)	Heavy
13	1340-1395 (2444-2543)	55 (99)	Heavy
17	1430-1480 (2606-2696)	50 (90)	Light
24	1420-1450 (2588-2642)	30 (54)	Very little
26	>1500 (>2732)		Light; hard
Apr. 8	1335-1370 (2435-2498)	35 (63)	Excessive; very hard, 18 to 20 in. in V and thick

L. P.
SCALE 1/16



H. P.
SCALE 1/72



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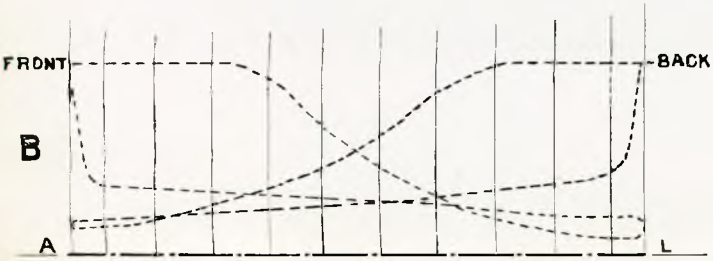

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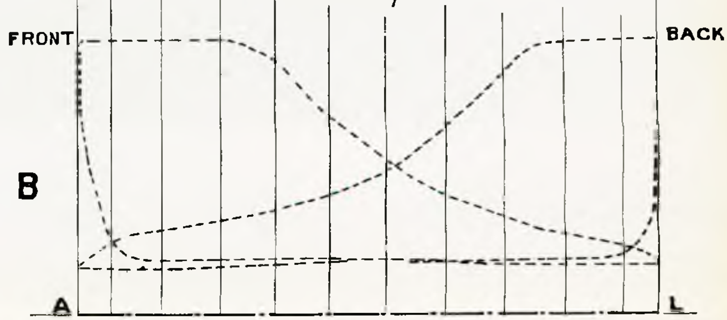

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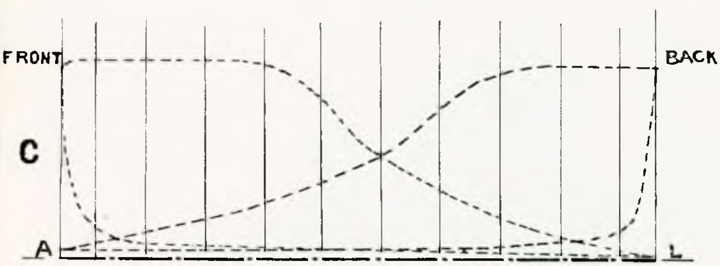

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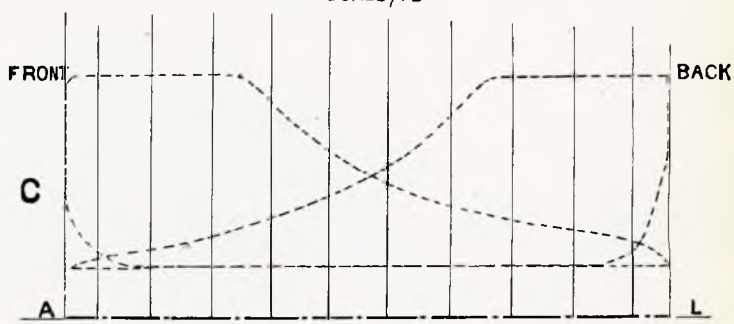

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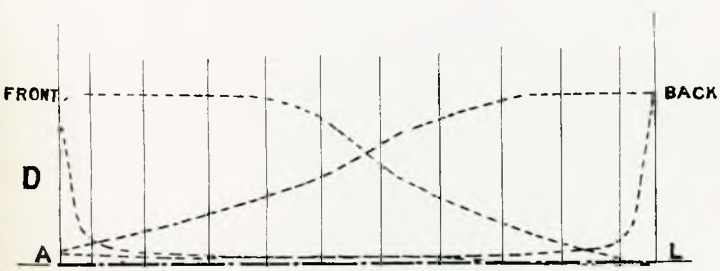

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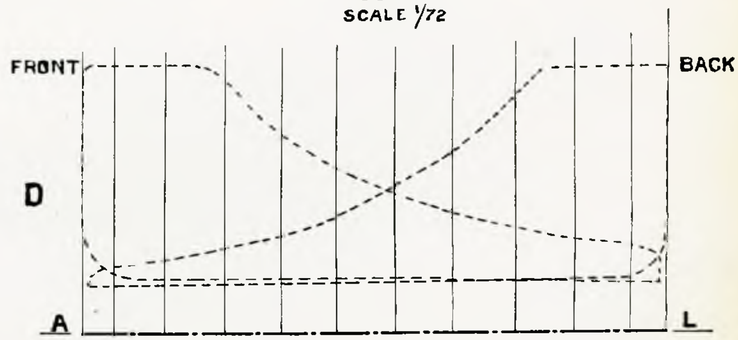

and the viscosity of the melted cone. The ash cones of February 10 and March 5 show the smallest range and they also show greater fluidity than any of the other cones. It should be noted, however, that there is a liability to error in observing the initial and final bending temperatures, which is not less than 10 deg. cent. so that an observed range of temperature of 30 deg. may actually be anywhere from 10 deg. to 50 deg. cent.; it is necessary to make several determinations in order to get the range with reasonable certainty. The appearance of the melted cone is consequently more valuable than the range of fusing temperature.

The investigations of the writer seem to show that under the conditions of combustion at the L Street plant of the Edison Electric Illuminating Company of Boston a coal with a fusing temperature (final bending) below about 1400 deg. cent. (2550 deg. fahr.) will probably give trouble if the ash has a fluid constituent; whereas, it will not give trouble above about 1380 deg. cent. (2516 deg. fahr.) if the ash is viscous. The conclusion would require further investigation with many other coals before it could be accepted even for this particular plant; naturally it cannot be applied to plants with different operating conditions.

ELECTION OF MEMBERS.

Members elected at a meeting of Council held on August 10th, 1915:—

As Members.

William Relph, 56, Russian Drive, Stonycroft, Liverpool.
William Percy Hawley, North Guards, Whitburn, Sunderland.
John Lander, Carbis Bay, Cornwall.

Transferred from Associate to Member.

R. B. Lyddon, King's Norton, nr. Birmingham.

Transferred from Graduate to Associate.

Ernest H. Jones, 5th Engineer, H.M.S. *Polmont*, *c/o* G.P.O., London.

Correspondence.

I have the honour to forward you under separate cover four sets of indicator diagrams obtained from a compound engine exhausting into a low-pressure turbine.

You will observe the loop on the exhaust line, and the high back-pressure on the L.P. cards marked A and B due to the steam being choked between the L.P. exhaust and the turbine. The steam, after leaving the L.P. engine, passes through an oil separator, before entering the turbine, between the oil separator and the turbine there is fitted into the steam pipe a perforated screen of very fine mesh. The perforations got filled up with grit and oil, thus preventing the steam from entering the turbine, and causing an excessive back pressure.

The other two sets C and D were obtained after the screen had been removed. The dimensions of the compound engine are as follows:—

Diameter of H.P. Cylinder ..	29 inches diameter.
,, ,, L.P. Cylinder ..	59 ,, ,,
,, ,, Piston Rods ..	7 ,, ,,
Length of Stroke	72 ,, ,,
Revolutions per Minute	59 revs.
Boiler Pressure	180 lbs.
L.P. Receiver	24 lbs.
Pressure on Turbine	*Nil.*
Vacuum	26·5 inches.

The engines are capable of developing 2,000 I.H.P. when running condensing, and the turbine 1,250 H.P. I hope these cards may be of interest to some of our members who have anything to do with low-pressure turbines.

With kind regards and best wishes,

I am,

Yours faithfully,

JOHN HANICK (Member).

CHRISTCHURCH,
NEW ZEALAND.
4/8/1915.

I note from the current number of *The Marine Engineer* that you are retiring from active work after a long and honourable term of service at the Royal Albert Dock. I trust, however, that it will be many years yet before you have to sever your connection with the Institute. I am only a junior member, but I may be allowed to express my opinion that we owe a great deal to your splendid work in the early stages of the Institute when the foundations were being well and truly laid by the foundation members, the visible results of which are seen to-day on Tower Hill in the fine building lately opened. On running through the report of the annual meeting I notice that several members are beginning to ask what we are to get out of the Institute from the monetary point of view, but personally, I consider that we get full value for our money from the excellent papers and the discussions thereon from time to time. One matter I wished to bring up was the Admiralty appeal on the back page. I think that I referred to this matter in a previous letter, but some months ago I applied through our department for any vacancy in the ranks of the Royal Naval Reserve, as a number of temporary commissions have been granted to sea-going engineers. A cable was sent to England, and after some delay, a reply per cable was received through the High

Commissioner stating that my services could not be utilised. Of course, I don't know how the cable was worded, but it seemed strange to me that with all the new warships fitting out at high pressure, there could be no opening. I may state that I was forty (40) years on June 3rd, and have now been with this department as Inspector of Machinery, Surveyor of Ships, etc., since 24/4/12. I can obtain leave of absence from the Public Service Commissioner, but as our staff would have to be rearranged I will require to give our Chief Inspector particulars of where my services would be required. I am writing under separate cover to the Superintendent, R.N.R. Forces, and will refer him to you.

Best wishes to Mrs. Adamson, the family, and yourself, from

Yours faithfully,

John H. Knowles.

The Initiation of the Institute of Marine Engineers.

A proposition has been made to the Council by Mr. Geo. Sloggett, Vice-President, Cardiff, that a photographic group should, if possible, be arranged, consisting of those who specially interested themselves in the earliest stage of the formation of the Institute, also that another group be arranged consisting of the Office Bearers, Members of Council, and Vice-Presidents for 1914-15, the year when the new premises were completed and opened, and that these historic groups be suitably framed and placed in the Institute premises. The proposer kindly offered to defray the cost of these, but it was considered that it would be more in keeping with the subject to place the charge to the general account. Mr. Sloggett presented £5 5s. 0d. to the Premises Fund, and has since presented a chronosphere for the Library. The photographs of all those who are referred to in these proposals are being obtained in order to form the groups. Should any member be able to obtain photographs of Mathew and Henry Prior such will be esteemed and returned when reproduced in the group.

TITANIC ENGINEERING STAFF MEMORIAL FUND.

The following letter gives an interesting report on the candidate, Maud Nicholson, who was admitted to the Royal Merchant Seamen's Orphanage last year, in terms of the arrangement made with the governors of the Orphanage under the auspices of the *Titanic* Engineering Staff Memorial Fund. The other case referred to is the son of a fireman who was drowned at Brisbane about 4½ years ago:—

> I am very pleased to be able to report very favourably indeed of both Maud Nicholson, who was admitted last year on presentation under the *Titanic* Memorial Fund, and also Ernest Suddell, in whose admission some four years ago you took such an active interest.
>
> The former is a sweet little child barely ten years of age yet, and is much loved by everybody. The latter is one of the best boys we have had in school for a long time, and is at present head boy of the school, as well as our finest athlete. He is entrusted, as Commodore Captain, with considerable responsibilities which he discharges with ability and zeal. He should do well in after life.
>
> Believe me, with very kind regards,
>
> Yours sincerely,
>
> F. W. Rawlinson,
>
> Secretary.