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Pulverised Fuel Firing with Special Reference to Power Station Practice.

READ

By S. B. JACKSON, A.M.I.E.E., M.Inst.F., (Member).

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Chairman: Mr. J. HAMILTON GIBSON, O.B.E., M.Eng.

Summary.

THIS paper deals with the general considerations affecting the direct-fired systems and central systems. It is suggested that the former system is obtaining considerably increased application in all countries, principally due to the lower initial expenditure. A section of the paper covers the combustion process and from an examination of it some useful conclusions are drawn. These are that high calorific value lower ash content coals of uniform grading as delivered to the burner provide the most suitable conditions for ensuring efficient combustion. The importance of preheated air and turbulence is pointed out, also that the bare tube wall ensures the highest heat liberation.

Trends in mill design, the importance of drying and the suitable selection of fuels are discussed. Some principal advantages of powdered fuel are elaborated in greater detail, and a table showing a comparison of a stoker-fired and pulverised fuel station thermal efficiencies is incorporated.

Aspects of dust and sulphur emissions are subjected to examination, and the opinion is given that public attention to these considerations, whilst desirable, may have a far-reaching influence on the location of generating stations or the cost of production of electrical energy.

The subject of costs is examined, in which connection it was formerly urged that there was a need for the standardisation of the methods of calculating the cost of production in electrical generating stations. This need has now been met.

Past influences of pulverised fuel on boiler design are outlined, and the major considerations affecting future development are indicated. The conclusion is drawn that pulverised fuel firing will find increased application and that rival systems of firing may be eventually displaced.

Introduction.

The advent of pulverised fuel firing is by no means recent. Its history has been chronicled in the pages of most scientific journals, not the least of which are the Transactions of our own

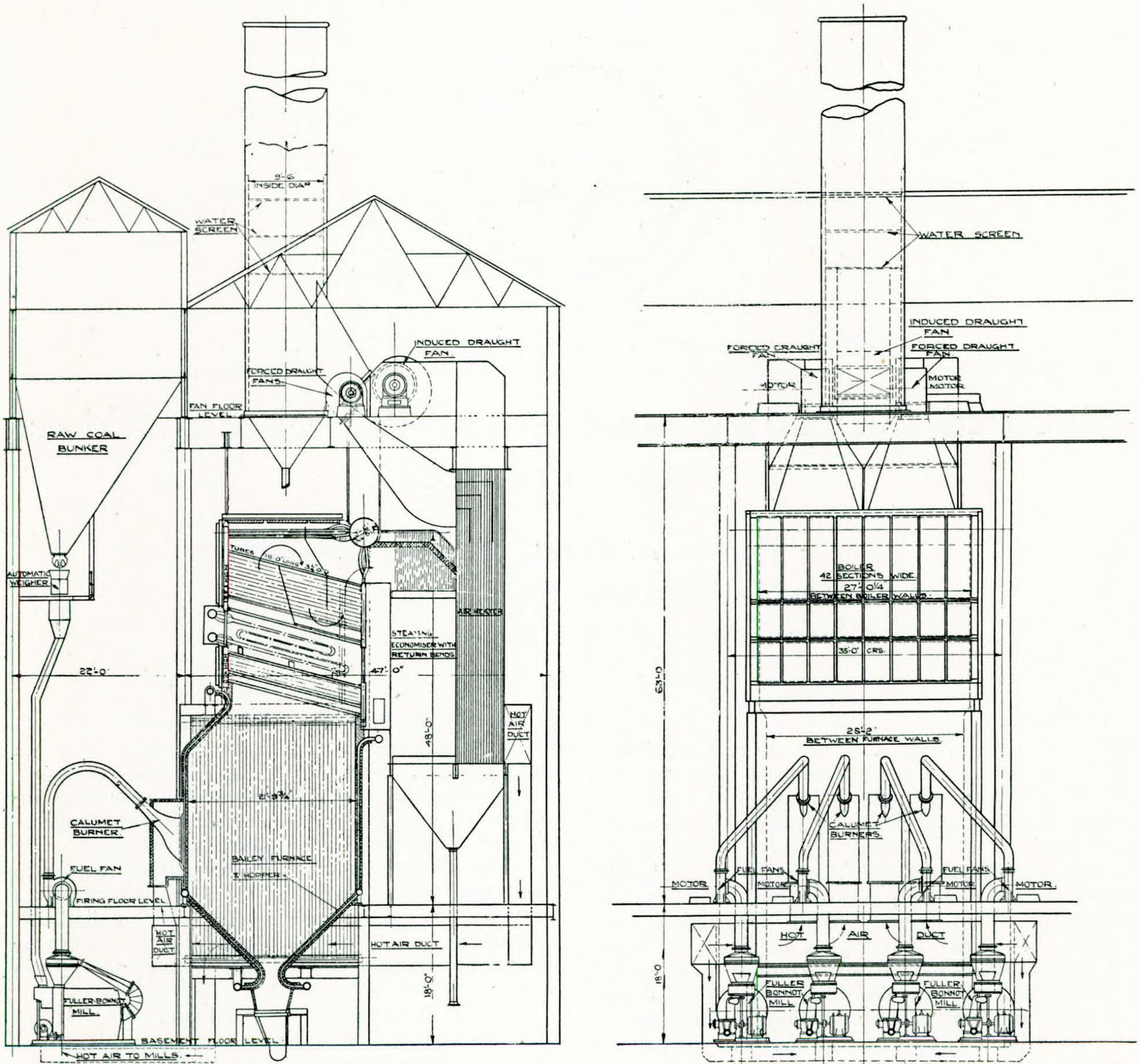


FIG. 1.—An example of a direct-fired boiler suitable for evaporations up to 300,000lb. per hr. The example is actually for 150,000lb. per hr. (normal economic rating).

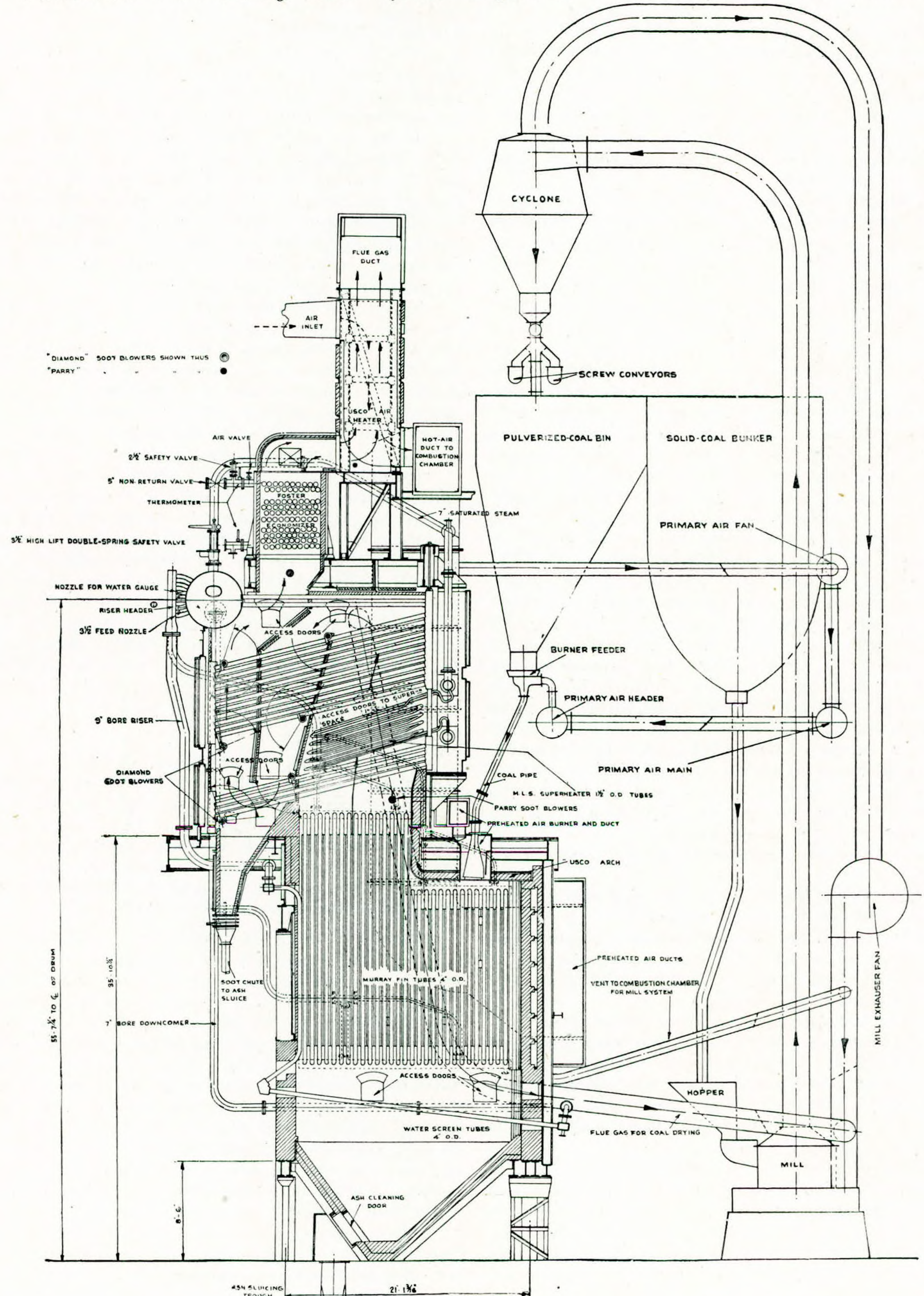


FIG. 2.—A representative example of a central installation in a large British power station. Evaporation 135,000lb. per hr. (normal economic rating).

Institute, in which are to be found many valuable contributions on the subject, especially with reference to marine engineering. As the author has no direct experience of marine applications, it is proposed to deal only with generating station plants, and to insert, where necessary, explanatory details which are common in both fields of application.

The growth of the science of electricity supply throughout the first fifty years of its existence has been so prodigious and electrical generating stations have become so important to the welfare of civilised mankind that they have secured for themselves a place amongst the nation's necessities. To such an extent has the application of electricity been developed, that an abundant supply of electrical energy is an integral part of the nation's industrial, commercial and social life. Considerations such as low price, a widely fluctuating demand, and the assurance of an absolutely continuous supply, therefore, assume tremendous importance. It is the object of this paper to study not only the relation of the application of pulverised fuel to this progress and to the foregoing considerations but to investigate its influence on modern generating stations, and to explore how it may affect progress in the future.

In this country development of electricity supply has been comparatively slow for a number of reasons which do not come within the ambit of this paper. It is, therefore, not surprising that many of the best examples of work in the development of powdered fuel installations are to be found not in this country, but in America, and to a lesser extent on the Continent. In discussing the applications to power stations, it is necessary to explore the utility, or, as some would say, the futility of them, and the questions which must be answered in such an enquiry are:—

(1) Does the application justify itself economically?

(2) Does it lend itself to the more efficient use of fuel and constructional material?

(3) Does it aid the operation of the large undertakings of to-day, and if so, how? and finally,

(4) Does it fulfil its duties better than any alternative method of firing?

This last question at once recalls the oft-debated supremacy of stoker firing over powdered fuel firing. It is not the object of the author to apply either heat or fuel of any description to this controversy, but to discuss the question impartially as time and supremacy itself will provide the most conclusive answer.

The foregoing tests are those which are usually applied to any piece of engineering apparatus, and in the opinion of the author one could reply in the affirmative with perfect confidence, but, for an engineering institution such as this one might be expected to qualify this answer in greater detail.

Fundamental Principles.

For the complete combustion of 1lb. of solid coal of a calorific value of 13,500 B.T.U. per lb., about 140-150 cubic feet of air are required, on account of the small surface area of coal exposed.

If this pound of coal is reduced to powdered form, the aggregate surface area of the particles, and the number of them, is very considerably increased. In the case of 200 mesh coal, there will be approximately 2,000 sq. ins. of surface area available, and if 85 per cent. of 1 cubic inch of powdered coal consists of this size, the number of particles is over forty millions.

When coal is reduced to particles, this permits the more effective association of air and coal because greater intimacy between the two exists. Providing there is an adequate amount of air available for combustion, the ignition of the coal particle is accomplished with great rapidity, due to the exposure of an enormously larger relative surface area to the heat in the combustion chamber.

In stoker-fired furnaces, about 25ft. of the total distance is required for the complete burning of the volatiles which are driven off owing to the presence of some form of incandescent arch, but in the pulverised fuel furnace it is necessary to produce violent agitation of the burning gases in order to effect the necessary association of the particle with the proper amount of air required for its combustion. This necessitates a longer flame and gas travel, which may be to the order of 35-40ft. and for this reason larger combustion chambers are required for pulverised fuel boilers.

Systems of Firing.

There are two well-known systems of pulverised fuel boilers, one being known as the unit or direct-fired system, and the other as the bin-and-feeder, or central system. The author prefers the use of the expressions "direct-fired system" and "central system" in indicating the two different systems. Figs. 1 and 2 illustrate direct-fired and central systems respectively.

Comparison of the Two Systems.

Very fine steam pressure regulation is secured on the central system, but in the direct-fired system it is somewhat coarser. Both systems lend themselves to the use of automatic electrical control, and where this is used there is little difference between the two systems. Any difference which does exist is to the detriment of the direct-fired system, as this system has no storage facilities, and also on account of the extremely small time elapsing between the reception of the coal in the mill and its delivery to the burner. Occasionally there may be sufficient coal in the mill to meet a minor emergency.

The central system more readily enables the concentration of pulverisers in separate houses, but this necessitates conveying plant which increases capital outlay and operating and maintenance costs. This system also permits the pulverising of the major portion of the station requirements at night when the supply system load is light. Hence the system peak load is relieved to a certain extent. When a pulveriser fails on the unit system the boiler output is restricted to the capacity of the mills left in service. This may be serious if it happens at the time of the station peak load, and this characteristic is, therefore, disadvantageous.

A comparison of the operating and maintenance costs of the two systems generally favours the direct-fired system. An absence of auxiliary fans to deal with cyclone vents (not to mention the objections to these vents themselves), and the absence of feeder, screw conveyor or other transport equipments are the principal reasons for this. In the direct-fired system electrical power and lubrication are continuously required, and mill wear may be slightly greater, owing to the fact that mills are running the whole of the time a boiler is in service. To supply direct current energy for the central system feeders, an additional transformation of electrical energy is required. This loss, although small, is not incurred in direct-fired systems. If the direct current supply is obtained through the medium of a rotary converter, the inherent instability of this machine under system disturbance conditions may cause the cessation of supply to the boiler feeders. In some installations, therefore, a stand-by battery is provided to deal with this emergency.

As regards maintenance costs, the use of additional apparatus increases the maintenance cost of the central system.

The abridged results of a test on a boiler in the Calumet station of the Commonwealth Edison Company are given below. The boiler capacity is approximately 220,000lb. per hour, and it was first fired on the central system, a conversion to the direct-fired system being made later. These results being strictly comparative afford a good guide as to the characteristics of the two systems. Maintenance costs were also published, but these were not comparable for several reasons.

TABLE 1.
COMPARISON OF CENTRAL AND DIRECT-FIRED PERFORMANCES.

Data.	As Central System.	As Direct System.
Period covered, months	24	11
Coal fired, tons	60,986	34,771
Steam produced, lb.	938,299,000	509,820,000
Actual evaporation, 1,000lb. per ton of coal	15,386	14,663
Steaming hours	7,124	3,479
Average evaporation per hour ...	132,000	146,500
Average coal fired tons/hours...	8·56	9·99
Steam pressure	310	314
Steam temperature °F. ...	676	678
Steam superheat °F.	251	253
Feed water temperature °F ...	182	209
Added heat per lb. steam B.T.U.'s	1,203	1,148
Calorific value of coal	11.037	10.314
Evaporative efficiency % (overall)	83·85	83·7
Total k.w. per ton	55·35	51·31

It will be noted that the direct-fired system required less electrical power per ton than the central system, despite the fact that the coal quality was inferior. The boiler efficiency fell, no doubt due to the class of coal used, but by only 0·15 per cent., which is not serious.

Owing to the simplicity of the direct-fired system the initial cost is lower than that of the central system. Summarizing the data obtained throughout the world shows that generally performance, availability and operating costs are approximately equal with a slight advantage in the direct-fired system. A definite saving in capital costs results on the installation of this system, consequently it is obtaining increasing favour. During recent years American and German practice shows that new installations of the direct-fired system are approximately 2·5 times that of the central system.

The Combustion of Pulverised Fuel.

The combustion of pulverised fuel is an extremely intricate and complex process, for it consists of thermo-physical, thermo-chemical and thermo-dynamic reactions acting almost simultaneously. These may take place partly in sequence, or partly together, but they are subject to a great variation. The combustion time of a particle of fuel is dependent upon its own constituent parts as determined by ultimate analysis, the fineness of grinding, the degree of turbulence, the size and type of furnace and the temperature of the furnace. It is, therefore, difficult to separate these factors in order to discuss them individually, and thus, the task becomes one of great complication to attempt to define in a clear and straightforward manner all the reactions involved.

The usual view of this process is that there is first of all a distillation period in which the volatiles are driven off, the volatiles are then ignited and swept away leaving the solid residue of carbon available for combustion. This explanation is very elementary and leaves much to be explained because other factors are involved.

A general view of the action will first of all be given, and subjected to a detailed examination.

On arrival at the combustion chamber radiant heat is supplied to the particle; this heat is derived from two sources, namely the burning gases and the furnace walls. The particle must first of all be dried, and this is achieved by endothermic or heat absorption action, and thus the temperature of the particle is increased, producing water vapours and distilled volatile vapours in turn. The distillation or de-gasification results in further endothermic action owing to the distilled vapours being black bodies. The surrounding air is heated by convection, and the temperature of the particles, gases, and surrounding air increases due to the rapid absorption of the radiant heat. As the distillation of the volatiles progresses, the ignition point is reached, and as ignition proceeds, it leaves behind the solid carbon residue. During this process under the influences of the evolution of gases and the expansion of the particles due to temperature, the particle may develop into a cenosphere, or it may disintegrate into smaller particles. In either case the effect is that rapidity of combustion is increased; in the one case by virtue of the larger surface area exposed, and in the other due to the increased fineness as a result of the dissolution which in fact amounts to an increase of surface area, and also due to the increased relative velocity imparted to the smaller particles upon splitting up. Combustion of carbon is accomplished in accordance with the laws of diffusion on the assumption that the required oxygen supply is available. This would be the case if the carbon particle were in a volume of pure air, but it is surrounded by burning volatile vapours, and this renders perfect association of carbon and oxygen very difficult. As these volatile substances are distilled they generate and absorb radiant heat, and the high luminosity thus produced makes available very considerable amounts of radiant energy. Thus the heat liberated is such that the temperature of the particle is very quickly raised and brought to the point at which combustion of carbon can be effected. Since the carbon is surrounded by burning gases the association with oxygen can only be partly accomplished by diffusion and it is therefore necessary to provide a considerable relative velocity of air and carbon not only to provide the requisite volume of air for combustion but to ensure that the vapours might be scrubbed away. If the relative velocity, or violent agitation of the gases is insufficient, coalescence of the particles may occur. Combustion will thus be retarded on account of the longer time factor to burn the larger particle and in addition the loss of unconsumed carbon will be increased.

Time of Combustion and Heat Liberation.

It can be shown that the time of combustion of a solid particle of carbon is dependent upon its radius, its density, and its relative velocity to air. Upon this assumption it is found that the time of combustion varies directly with the radius and inversely as the relative velocity of air and carbon. The fineness of the particle will, therefore, affect the rate of combustion, or alternatively an increase of the relative velocity of air and the particle will produce accelerated combustion. For a coal particle much the same state of relationship exists, but with this difference, that in the case of carbon and air no impediment is present to the absolute freedom of combustion of the particle except the formation of CO and CO_2 around it. In the case of coal its carbon particle is surrounded by a mist of heterogeneous burning vapours. Further, whilst the consumption of the particle may be retarded for that reason, it may be accelerated due to the gradually diminishing size of the particle consequent upon the distillation of the volatiles and its own combustion. When it is considered that the chemical constituents of the particle, and the volume and calorific value of the volatile matter exert further influence on the combustion time, the problem is further complicated. It has been stated that owing to the evolution of gases and the possible expansion of the particle, it may disintegrate into smaller particles, crystals, flakes or cenospheres. The time to consume a cenosphere may be up to one-fiftieth of the time taken to consume the original particle of coal. Cenospheres are formed only if coking coal is used. This partly explains the reason why the bituminous coals burn better than non-coking low volatile coals. In addition, ignition is much easier, and this is due to the heat absorption process upon which a greater volume of black vapours is formed.

The original particle has been assumed to be spherical, but in practice this may not be so. The probability is that it takes the form of flakes or crystals. Therefore, the surface area of the flake may be larger than that of a sphere, and due to this the combustion time may be further reduced.

Having regard to these considerations it is recognised that it is an extremely difficult task to show the exact relations between combustion time and the fineness of the particle, etc. The heat liberation and size of particle relation is equally difficult to obtain, but Dr. Ing. Rosin has obtained values which are sufficiently accurate to fairly represent what happens in practice. It is stated that the relations thus obtained are valid only over a certain range and outside this they do not represent actual conditions. From his observations he concludes that it is possible not only to determine an approximate heat liberation relation, but for any desired burning time the unconsumed portion of the fuel remaining, for it is evident that as the particles vary in size each would have a different combustion period. On account of this non-uniformity of particles being delivered from the mill a certain amount of loss must result. The present author would venture to suggest a further reason for this. The larger particle being in a highly reactive state, and possessing a considerably larger surface area will attract to itself a larger amount of oxygen, thus tending to deprive the smaller particle of its proper supply. Since this supply is very quickly consumed by the distilled volatiles higher excess air requirements are necessitated. The combustion time is thus not only dependent upon the fineness of the particle but upon the average fineness of the total supply, and evidently, it is equally essential to provide uniformity of particle size as to provide for fineness of pulverisation.

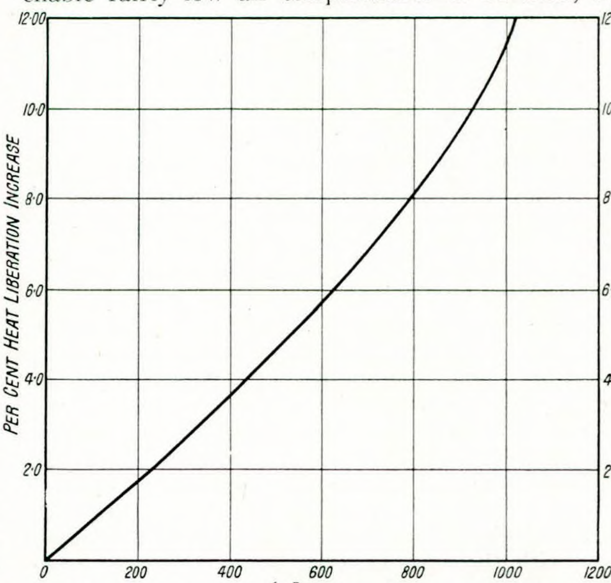
Combustion characteristics have been determined on the assumption that the loss of weight by combustion of the particle is proportional to time, this reconciling with the usual views of the combustion process. This process is assumed to be first of all de-gasification of the particle, then the solid particles are ignited, and these ignite in turn the liberated gases which burn with high velocity and temperature, and finally consume the degasified residue. According to one investigator the definition of true combustion is the elementary oxidation of water gas components CO and H_2. These being absent in the initial fuel state, combustion proper is assumed to be preceded by a period of conversion of the fuel to a state of readiness for combustion, consisting of the pyrogenic decomposition of the fuel and the addition of oxygen up to the ignition point being reached. Thus, the actual combustion process is really discontinuous, consisting of two stages, the conversion to a state of readiness, and combustion proper. Continuing on this theory it can be determined from the characteristics whether complete or almost complete degasification takes place before the ignition point is reached because the ignition of the fuel requires a definite time, and this depends mainly on the thermal conductivity of the fuel to raise it to the ignition temperature. If the ignition delay is too great the combustion is effected immediately in front of the tubes, and "bird-nesting" is formed.

Heat Liberation and Temperature.

It can be shown that the rate of heat liberation in a furnace is dependent in a two-fold manner upon the furnace temperature. With increasing furnace temperature, the time of combustion falls because the combustion process is accelerated, and thus the heat liberation is increased. On the other hand, with a decreased furnace temperature the heat liberation may be increased. Take a case of a furnace with uncooled walls, the heat liberation will represent a certain value, but with cooled walls the rate of heat transference will be increased due to the flame imparting its heat almost immediately it is kindled to the heat transfer surfaces, and hence the average furnace gas temperature is decreased. In regard to the former reason, it will be observed that the heat liberation is dependent upon rapidity of the transformation reaction, but in regard to the latter it is dependent on the ability of the transfer surfaces to rapidly absorb heat, and hence the mean temperature of the furnace is lowered. These two influences to some extent counterbalance each other, but not completely, for the one which determines the speed or velocity of reaction predominates. It can be stated, therefore, that for each furnace there is a certain definite temperature, assuming the utilization of a particular class of coal, at which the maximum heat liberation can be obtained. This temperature is that at which the maximum transformation or conversion reaction is accompanied by the maximum heat transfer rate. Upon this assumption the rational design of combustion chambers should consist entirely of heat transfer surfaces, for the bare tube wall permits of the greatest radiation to be attained on account of being a black surface. This explains the reason for the increasing popularity of bare tube walls and a tendency towards their increasing use in the future.

Preheated Air.

We have considered the question of the conversion of the fuel to a state of readiness for combustion. The degasification period is but a part of the total period taken for readiness to be achieved. The development of the gases accelerates the process, for as the volatiles are ignited upon emerging from the particle they radiate heat back to it. This conversion period is almost entirely a heat absorption process and as such the temperature of the particle is very rapidly increased. Therefore, anything which can accelerate the process will result in an increased heat liberation from the furnace. It is thus necessary to provide some means for ensuring an increased initial particle temperature. This can be achieved by the application of preheated air. Cold combustion air only delays the combustion period and this explains why superior combustion performance is obtained in furnaces using flue-gas drying at fairly high temperatures since the initial particle temperature, and the temperature of a portion of the combustion air are higher. Coals which possess a high volatile content enable fairly low air temperatures to be used, but



Air temperature above boiler house temperature.
FIG. 3.—Relation of Increase of Heat Liberation to Preheated Air Temperature.

low volatile coals demand a high pre-heat temperature in order that they may be quickly burnt. Fig. 3 shows the rate of increase of heat liberation plotted against the initial pre-heated air temperature, and it shows that pre-heating is economically sound.

The heat absorption of the boiler surfaces exposed to the flames is proportionate to the fourth power of the temperature difference between the flame and the boiler surface. Therefore, assuming a constant tube temperature, the raising of the furnace temperature by the use of the pre-heated air considerably increases the heat transfer rate of the boiler.

Difficulty has been experienced in preheater operation which is attributable to the dew point. The temperature of the flue gases must not be low enough to allow moisture precipitation on the cold portions of the heater or on those parts of the preheater system traversed by the flue gases. The effect of sulphurous flue gases is particularly marked because damage may be caused to the heater. Correct heater design and judicious choice of coals minimise this danger.

It can, therefore, be concluded that the use of preheated air enables the most efficient use of material, since less fuel is required for a given boiler output and, alternatively, a higher output can be obtained from a given boiler and furnace.

Turbulence.

One more influence remains to be discussed and this is turbulence. The size of a particle is extremely small, and it possesses very low momentum. The viscosity of the fluid in which it moves increases with temperature, and thus the penetrative power of the particle is decreased. It thus rapidly attains the velocity of the carrying air, in which state it does not acquire the necessary amount of oxygen to complete combustion without the use of some medium to bring it into more intimate contact with the necessary volume of air. As the gases have been distilled off, the size of the particle is now considerably smaller than it was originally and its combustion is further retarded because it is enveloped in a cloud of burning vapours. It is thus vitally necessary to secure the destruction of the envelope to admit the oxygen component. If the particle be now considered as the centre of a sphere of burning vapours, and these being incapable of supporting combustion, it is not difficult to imagine that the oxygen concentration at that point is extremely limited. As supplies of oxygen are consumed the sphere or cloud increases, and thus it becomes increasingly difficult to furnish fresh supplies. As the vapours rise they carry away with them supplies of air which have been heated by them; if the particles were left in this state complete combustion would be impossible, and the heat liberation would be limited. It is therefore necessary to secure a high degree of turbulence to increase the reaction velocity. The separation of the particles is important in order to secure the maximum surface contact with air. It has been aptly expressed that " the dust is blown into the furnace in a comparatively thick jet, so that what has previously been separated at the expense of power and money is re-united in the burner." It is most essential to create the potential surface into free reactive surface. This can be accomplished by burner design, correct air flow, and the maintenance of a high order of fineness of pulverisation. As the particle becomes smaller the relative velocity decreases, so that greater turbulence is necessary.

Conclusion to Part 1.

Sufficient has been written to indicate the nature of the problem. Pulverised fuel firing presents a wide field for research, for many difficulties remain to be solved. Summarising what has gone before, in order to obtain the best results from pulverised fuel it is necessary to adopt the following measures :—

(1) To utilize coals of high calorific value with high volatile content and low ash content. Ash reduces the heat content of the fuel and hence the potential heat liberation.
(2) To maintain the fineness of pulverisation as high as possible. This chiefly depends upon economic considerations such as cost of mills, grinding, and power consumption.
(3) To ensure uniformity of particle size delivered to the furnace.
(4) To use furnace walls consisting of heat transfer surfaces, thereby eliminating refractories.
(5) To apply pre-heated air.
(6) To ensure the maximum turbulence.

Relation between Primary Air and Coal.

The correct relation between the primary air supply and the coal which it carries depends on the volatile and ash content of the fuel. Considering the theoretical aspect of this relation, Fig. 4 shows the speed of flame propagation for various ratios of fuel and air mixtures and for a few different types of coal. These have been determined by Audibert.

The curve representing 30 per cent. volatile matter and 15 per cent. ash content may be taken as representative of a typical coal used in many powdered fuel installations and it is observed that maximum flame propagation occurs with a mixture of 3¼lb. of air per hour per lb. of coal. The curves are illustrative of the fact that as the volatile matter is increased and the ash content reduced, better combustion conditions result. It will be also noted that with low volatile coals the maximum propagation speed is obtained when the ratio of air to coal is lower, and for anthracite it is found that less primary air is necessary, or alternatively, a larger burner which will discharge the

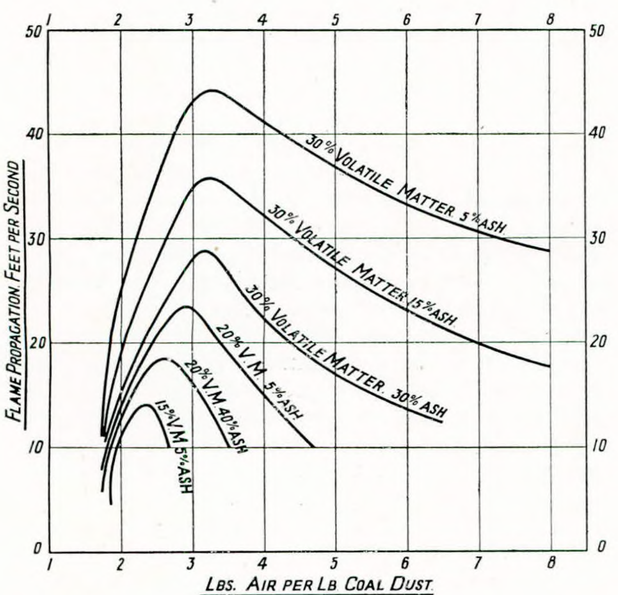


FIG. 4.

mixture at low velocity should be employed.

It is necessary that the velocity at which any given mixture is discharged from the burner should be greater than the theoretical speed of propagation, otherwise back firing will occur. If, however, the velocity of the mixture is very much greater than the flame propagation speed, ignition will occur some distance from the burner and unsteadiness of flame will result.

In the direct-fired system, the primary air is a separating medium for the coal particles, and the velocity of the air through the mill must be such that it does not drop below a certain minimum value. This results in high air to coal ratio at low loads, but this decreases as the mill output is increased.

The maximum air to coal ratio is about 2lb. of air to 1lb. of coal and the velocity of discharge may be as high as 140ft. per second. With a low coal output from the mill the ratio may be as high as 6lb. of air to 1lb. of coal, but unless care is taken in the burner design, difficulty may be experienced with unstable combustion conditions, especially when lighting up boilers. In the central system, the quantity of primary air may be regulated independently of the mill air requirements and provided the minimum air speed required to convey the necessary coal quantity through the pipes is maintained for each load, the normal combustion ratio of air to coal is usually maintained over a wide range of load.

The quantity of primary air is determined by the required burner velocity, and the amount of secondary air required is the balance of the furnace requirements.

It will be seen that the curves demonstrate the value of utilising coals of high volatile and low ash contents, and they seem to lend support to the conclusions given in the section of the paper dealing with the combustion of pulverised fuel.

Expressed in terms of total combustion air, the ratio of primary air varies between about 10 per cent. and 35 per cent. This latter figure is for direct-fired systems at low loads. The primary air may be heated, and temperatures of 120° F. up to 350° F. are being used. In direct-fired systems where flue gas drying is used the temperature is, of course, that of the drying medium.

Suitable primary air and burner control permits the flame to be deflected upwards or downwards as desired. At high loads the flame may be brought to a sufficient distance below the tubes to prevent "bird-nesting." On low loads the flame may be projected upwards to a point nearer the tubes, thus ensuring a better efficiency.

Drying.

The drying of coal is necessary for a number of reasons. In the first place, the presence of moisture in any form reduces combustion efficiency, and in consequence reduces the boiler effective capacity. Further, in the case of milling, the mill capacity is reduced, and the power consumption increased, while the fineness of the product is affected. In addition to these disadvantages, the handling of the pulverised fuel is rendered more difficult, and to some extent the flexibility of boilers is reduced. The electrical energy per-ton-pulverised is a function of the moisture content, and the relation can be easily calculated if the usual characteristics of the dry coal are known. It is possible that the variation of power may be of the order of three to six units per ton. Little more need be added to show that considerable advantages are gained by the drying of coal.

It has been suggested that it is only the surface moisture which affects the handling or workability of the coal. This is true where the hygroscopic moisture does not exceed about 2½ per cent. In British coal this moisture may reach about 7 or 8 per cent., and assuming no surface moisture being present, the contention seems difficult to support.

Drying is accomplished by two methods :—

(1) Drying machines (dryers).

(2) Drying by flue gases.

The first method is being rapidly superseded by the latter, and in many instances conversions to the latter method are being effected. In new installations flue-gas drying or hot-air drying is standard practice. It is hardly necessary to describe the old method, as no useful purpose could be served thereby.

In flue-gas drying the flue-gas is brought into contact with the coal in the mill. In direct-fired systems a gas duct is taken from a suitable point in the boiler and led to the mill, the flue-gas being returned to the boiler with the mixture of coal and air. The flue-gas may be mixed with a suitable proportion of air before arrival at the mill. Various means, such as louvres, or air inlets, with damper control are used for this purpose. Only a very small proportion of inert gas is delivered to the burners; expressed in terms of CO_2 it may not reach a figure of 0·05 per cent. The effect on combustion conditions is negligible. In central systems a supply of flue-gas is delivered to the mill from which the gas and coal mixture is passed to the cyclone. The cyclone vent discharges either to atmosphere or into the furnace, being delivered to an auxiliary burner by means of a small fan. Alternatively, the vents are returned to the mill-cyclone circuit. These two methods result in the utilisation of coal dust which would otherwise be discharged to atmosphere, and a slight economy is thus secured.

In one installation, namely, that of the North Metropolitan Electric Power Supply Company at Brimsdown, a small furnace is specially provided for each mill unit to supply the necessary flue gas for drying. The reason for this is that the mills for the central fired boilers are in a separate pulveriser house, and the temperature drop in the flue-gas duct would have been quite considerable. It was, therefore, considered preferable to instal these furnaces nearer to the pulverisers. If the coal is very wet an oil-fuel burner is used as a booster. This installation works with complete success.

The amount of moisture which can be effectively removed by flue-gas drying is of the order of 18 to 20 per cent. Fortunately, the latter figure is not met with frequently in practice. When it is, it must not be expected that full boiler output can be maintained. On the contrary, large quantities of water vapour reduce combustion efficiency, although the workability of the fuel may be excellent. The proper temperature to be maintained at the mill inlet depends to some extent upon the humidity of the air, for under certain conditions the dew point of the coal-gas-air mixture will be low, and, thus, the coal delivered to the burners will be moist. The presence of sulphur in the coal is objectionable because the dew point is therefore lowered. Combustion conditions are thus affected if proper drying is not achieved, and the risk of "bird-nesting" of the tubes is increased. To eliminate any possibility of this, it is advisable to maintain a mixture temperature of not less than 180° to 190° F., and the inlet flue gas should be adjusted accordingly. The gas inlet temperature corresponding to this burner temperature is about 400-450° F. The central system presents special problems, and it may be inadvisable to employ delivery temperatures of 180° F.-190° F. on account of storage difficulties. It may be desirable to limit it to 110° F. to 120° F. to reduce the risk of combustion. Another problem in this system is that of the water vapour affecting the stored contents of the bunker, rendering the handling of them through the feeders very difficult. When it is remembered that the temperature of the drying circuit may be of the order of 400-450° F., it is obvious that air at this temperature may possess a considerably higher water vapour content held in suspension than at lower temperatures. Thus, when the coal enters the bunkers at the temperature of 180° F. say, it possesses a considerable amount of condensed water vapour. Combined with this, is the fact that the surface area of pulverised coal is very much greater than that of solid coal, and the area exposed to the water vapour is very large. As a result it will absorb a higher proportion of surface moisture, the amount depending upon the temperature of the drying circuit, the fineness of the coal, the ambient air temperature, and its humidity, upon which the dew point depends.

Fire risk is increased where gas-drying is used, and the tendency appears to be towards an increase in the volume of flue gas used and to restrict the air quantity in order to increase the CO_2 content of the circuit. In some American installations, CO_2 contents of up to 10 per cent. have been used and it is claimed that the product of the mill suffers neither from volatilisation nor from fire owing to the high temperatures employed. In America the ignition temperature of the volatiles is, in general, slightly higher than that of British coals and this may be partly the reason.

Pre-heated air is being successfully used for drying in a number of cases.

Automatic temperature control equipment for drying circuits is being used with success, and there are indications of a tendency towards the extension of its use. Recent experiments show that unit systems operate more satisfactorily under automatic conditions than central systems. The control is only in the experimental stage at present but the author forecasts greater application in the future.

The handling of wet coal before delivery to the mill deserves attention. The slack coals which are chiefly used in this country often arrive at the power station in uncovered wagons, and the moisture content is very considerable. Difficulty has been experienced in a number of installations in getting the coal from the bunker to the mill. The restricted orifice from the bunker allows the coal to fall through the usual 2 cwt. weighers, and when dealing with coals of 10-15 per cent. moisture content frequent choking occurs, sometimes leaving the mills empty. This is obviously undesirable in any installation. Chutes also frequently choke and these should be made sufficiently vertical to allow an easy passage of the coal. In future boilers of say 350,000-500,000lb. per hour, 8 cwt. weighers will, no doubt, be used and it would appear that as boiler sizes increase this difficulty will be simultaneously overcome.

In electricity supply undertakings where continuity of supply is of paramount importance, small details such as these should be given greater attention.

Slagging and Combustion Chambers.

Much difficulty has been experienced in this country on account of slagging of the ash. The difficulty was due to two causes, namely, the generally low ash fusion temperature of British coals and the high ash content. As a result of the great inconsistency of fuel supplies it is difficult to design combustion chambers to work with a given class of coal, especially with regard to the ash fusion temperature. Considering that it is somewhat precarious to predict the performance of a coal from its chemical analysis only, the problem is to some extent aggravated. Even a knowledge of the ash fusion temperature is insufficient, for at certain temperatures simultaneous coking and ash fusion may result.

In America combustion chambers can be suitably designed for a definite class of coal and thus the problem is greatly simplified owing to the general consistency of all characteristics of each class of fuel. Where refractory walls are used the problem of maintenance is very serious. If the wall temperature is lower than the slag temperature the slag impinges on the wall and spalling results due to the different coefficients of expansion of the two materials. This is the more usual result of slagging. On the other hand, if the wall temperature is higher than that of the slag, as may be the case with a very low ash fusion temperature when the CO_2 being maintained is very high, erosion of the wall will result. In the case of "bird-nesting," which may be due to the combination of the collection of coked material and fused ash, the slag may bridge the lower row of tubes and the mass may assume serious dimensions, which may be sufficient to strain them. To remedy this, it is essential to ensure the expiry of the flame some distance away from the first tube bank, or if the use of coals producing such results is to be continued, a slag screen becomes necessary. Slag adheres to this screen, which consists of a bank of tubes of wide spacing located about 3ft. below the main steaming bank, and the spacing is wide enough to prevent serious accumulations. In the event of the gap being bridged the slag will break off under its own weight and leave the gas passages unobstructed.

In addition to these troubles, fluxing of the refractory may be caused. When coals possessing high pyrites and sulphur contents are used the ash becomes a flux for the refractory and serious melting of the furnace wall may result. To eliminate this undesirable feature special bricks were necessitated and in consequence the cost of walls was increased. The principal ingredients of these bricks were silica and alumina, but more recently oxide of zirconium has been used. Being unaffected by the high temperatures and acting as a neutralising agent to the oxides created during combustion conditions, this metal is very suitable for furnace walls.

The prevention of tube slagging is greatly assisted by the provision of a large area of combustion chamber cooling surface so that the temperature of the gases may be reduced below the ash fusion temperature before they enter the main steam generating bank. It is undesirable to mix two coals of low ash fusion temperature because this results in the more rapid slagging of the ash, due to the lowering of the ash fusion temperature. Work along this line of research is in its initial stages only. It is unsafe to give full reasons for this phenomenon without further investigation.

Mention has been made of the increasing popularity of the bare tube wall because of its high heat transfer rate. In addition, owing to its comparatively low temperature, which may not exceed 800° F., when the slag is projected on to the relatively cold surface it contracts and falls to the furnace floor. The temperature of the gas about a foot away from the wall is considerably lower than that in the middle of the furnace and immediately the fused material enters this zone substantial cooling occurs before it reaches the wall, despite its high velocity. Incidentally, slag has a very low rate of heat transmission, and hence it acts as a heat insulator. Freedom from tube slagging ensures highest economy in heat transference.

The furnace temperature may be maintained sufficiently high to keep the slag running continuously in order to facilitate slag removal. In this case slag-taps are used, and simultaneously with the satisfactory slag disposal, high thermal economy is thereby ensured. CO_2 contents of over 16·0 per cent. may be expected to become regular practice. To prevent solidification of the molten mass as it runs from the slag orifice, the orifice must be kept at high temperature, and to secure this, part of the furnace wall tube arrangement is usually incorporated in the orifice design. To keep the material immediately above the orifice definitely molten it may be necessary to utilize an auxiliary burner, the flame from which expires just above the orifice. Alternatively, the flame from the main burners may be suitably projected to discharge this function. To facilitate the flow of the slag from the furnace the design should incorporate the use of ground ganister blocks, as slag does not adhere to this material. In the event of small accumulations being formed they are easily removed. As the slag cools, owing to its high coefficient of expansion its removal is very easy, as it contracts very rapidly. Water sprays are used to disintegrate the mass more completely before it falls into the ash sluice. To assist the flow inside the furnace a layer of burned dolomite is used, adherence being thereby obviated. Various materials have been used for this purpose, but burned dolo-

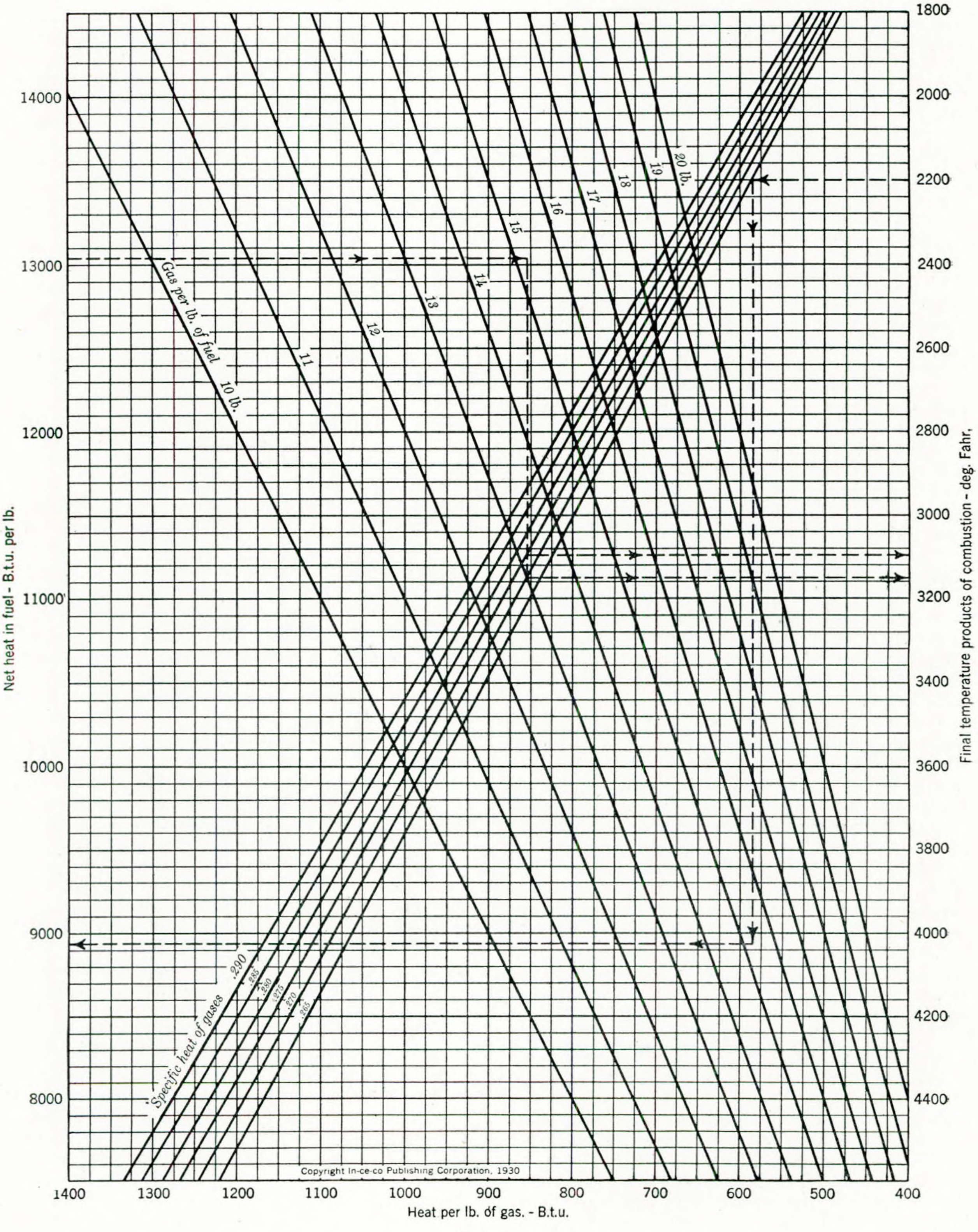


FIG. 5.

(Reproduced by kind permission of "Combustion", New York, U.S.A.).

mite has been found satisfactory. Gravity flow should be utilized to the full, and therefore the orifice should be placed immediately below the combustion chamber and preferably at the centre. Slag weighs anything from 150lb. to 200lb. per cubic foot. It is necessary to provide ample water pressure in the ash sluicing arrangements, and where gravity flow is used the decline to the ash settling sump should be considerable.

In air-exhauster ash handling plant, owing to the great weight of the slag, frequent choking of the ash pipes occurs.

The introduction of the water-cooled wall has enabled the heat release rating of the furnace to be considerably increased, for whereas, with an air-cooled solid brick refractory wall the average rating was approximately 15,000 B.T.U's. per cubic ft. per hour, with a water-cooled wall the rating increased to 30,000 B.T.U's. per cubic ft. per hour. With the use of tangential burners which produced greater turbulence, the rating was increased to 35,000 B.T.U's. per cubic ft. per hour.

Considering the nature of the bare water wall it might be reasonable to expect after more experience maximum rates of over 100,000 B.T.U's. per cubic foot per hour. With the enormous volumes of ash to be dealt with at these ratings if certain classes of coal are used, this figure may, of necessity, be considerably reduced.

The extent of the use of tube walls may be influenced by another factor, this being the actual operating limits of the boiler loading. With small furnaces the boiler flexibility is restricted owing to the absence of stored heat in the furnace walls. It may be necessary to incorporate refractory surfaces in designs where combined flexible and economical operation is required.

The trend in electrical system operation is to operate boilers on a constant loading, using one or two boilers only to cater for the station load variation. This method will, in the near future, become a definite practice and the problem of combustion chamber design may be rendered less difficult.

A Useful Chart for Pulverised Fuel Boiler House Use.

The chart given in Fig. 5 can be used for the determination of the theoretical combustion temperature in the absence of a pyrometer.

Taking a coal of 13,500 B.T.U's. per lb., if the hydrogen content as burned is 5 per cent., then the available heat is obtained by the use of the expression

$$9H_2 \times 1050$$

in calculating the loss due to water vapour which must be subtracted from the total heat.

Thus $13,500 - (1050 \times 9 \times \cdot05) = 13,030$ B.T.U's. With 13 per cent. CO_2 the approximate total gases will be 15·25lb. per lb. of coal. Reading 13,030 on the left hand scale, trace horizontally to the point of 15·25 from the flue gas. Then trace vertically to the specific heat of the flue gas, which in this case is ·270. From this point, trace to the right-hand scale and the temperature is given as 3150° F. It is found at this temperature that the corresponding specific heat for this coal should be ·275. Retrace from the ·275 point and the actual combustion chamber temperature of 3100° F. is given.

If it is assumed that the ash fuses at 2200° F. it is necessary to reduce the combustion chamber gas temperature to 2200° F. Tracing from the right hand scale at 2200 to the new specific heat of the flue gas which is now ·267, then dropping downwards to the flue gas point of 15·25lb., from this intersection we read on the left-hand scale an available heat of 8930 B.T.U's. This last application can be used in the design stage, but by similar application the new furnace conditions suitable to the ash fusing temperature can be obtained. The chart must be used in conjunction with a curve showing temperature of gases against their mean specific heats for the classes of coal used.

Pulverising and Particular Items of Plant.

There are three principal types of mills in use: the ball, impact, and Raymond types. These three categories have a number of variations in design, and their operating characteristics are different. Briefly, these characteristics are as follows:—

Ball type.—Low maintenance, simplicity.

Impact type.—Low power, high maintenance.

Raymond type.—Low power, medium maintenance.

The required fineness of the coal is chiefly dependent upon the hardness of the coal and the

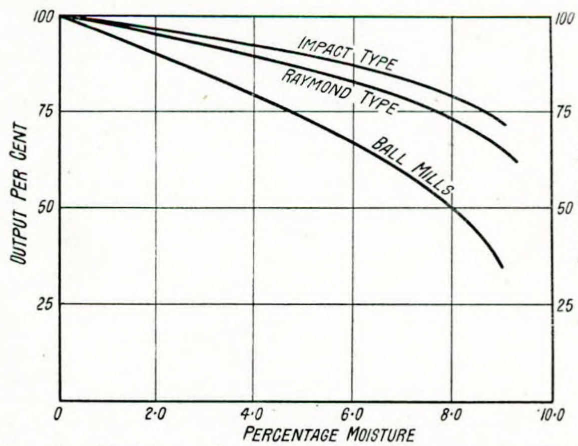


FIG. 6.—Showing effect of moisture on output of mill.

economical cost of pulverising. The main characteristics of these types of mill are given in Figs. 6 to 9. The curves are self-explanatory.

The mills with which the author has had experience are of the Fuller-Bonnot, Hardinge and Raymond types, the first two being of the ball

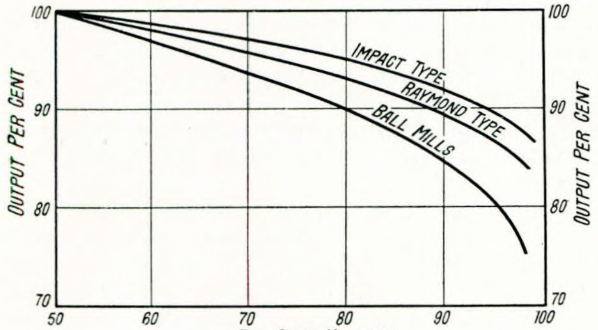


FIG. 7.—Relation between mill output and humidity.

type. Short descriptions of these will now be given.

The Fuller-Bonnot mill consists of a revolving cylinder in which steel balls reduce the coal to a powdered form. Coal is delivered to a feeder of the turntable type, and after pulverising it passes through a cylindrical classifier, and then to an external classifier. These classifiers control the quality of the fuel delivered by the exhauster to the burner. The proper speed of the mills is directly related to the internal diameter, and is slightly less than the critical speed. The critical speed is that at which the balls next to the internal circumference of the shell cling to the shell as it revolves. For a given size ball this speed is given by Davis as :—

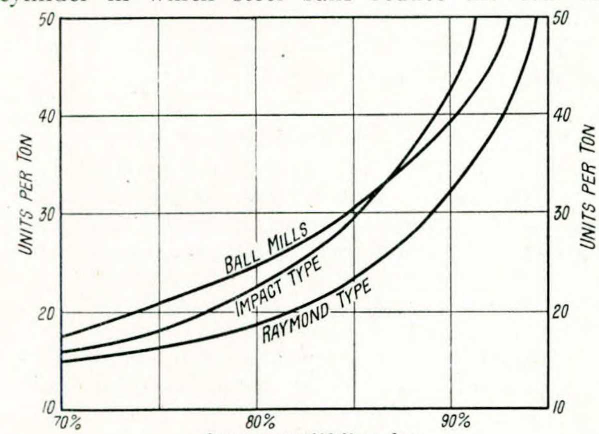


FIG. 8.—Relation between power consumption and product fineness.

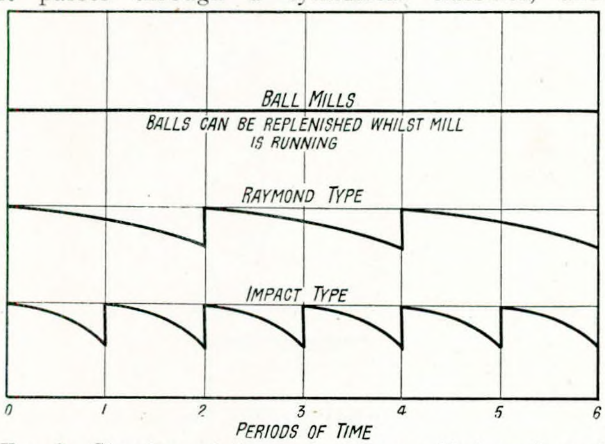


FIG. 9.—Showing relative wear to a specified grading of mill product on each mill type.

$$N = \frac{54{\cdot}19.}{\sqrt{r}}$$

where N = revolutions per minute

r = radius of internal circumference in ft.

At ·8 critical speed the balls tend to cascade and cause greater impact and at ·6 critical speed they tend to roll and cause greater attrition. The ball size is 1in. diameter upwards. If the number of balls is increased (but not above a certain value) the output is increased because of the greater grinding surface area. Power requirements are directly proportional to the speed. This type of mill is very reliable, and if proper attention is given to lubrication and the changing of balls it is a very useful mill. If tramp iron finds its way into the cylinder it serves as additional grinding surface.

In the Raymond mill, which is shown in Fig. 10, suspended rollers mounted on individual pendulums supported on a spider crush the coal between them and a bull ring. The coal is delivered to the mill by means of a ratchet type of feeder and is thrown by centrifugal force against the bull ring. Usually six pendulums and rollers are provided; the rollers may be up to 18in. in diameter, and the width up to 1ft. The speed of the mill may be up to 100 r.p.m. and thus the relative grinding area is very large. Separation of the finished product is obtained by the air current which enters the grinding chamber through a series of openings extending right round it, passing up through the coal on its way to the cyclone, carrying the coal in suspension. The mixture leaves the top of the mill, via a pipe connected to the cyclone, and thus the draught being fixed only coal within a given quality of fineness is exhausted from the mill.

The Hardinge mill, illustrated in Fig. 11, is a horizontal conical-shaped mill revolving at a low speed in which the grinding is effected by the attrition between a large number of various sized steel balls. The feed is at the larger end of the cone, and the delivery at the other end. The larger sized balls remain at the top of the heap, as does the largest sized coal. Thus classification is automatically obtained, and the largest material is crushed by the largest balls at a point in the mill where there is the greatest height or fall, and the highest peripheral speed. As the material advances towards the delivery end the product is finer, and thus the crushing force necessarily is less. The grinding media automatically separate themselves to ensure this. This mill delivers a very fine product and is being built in sizes up to 50 tons per hour.

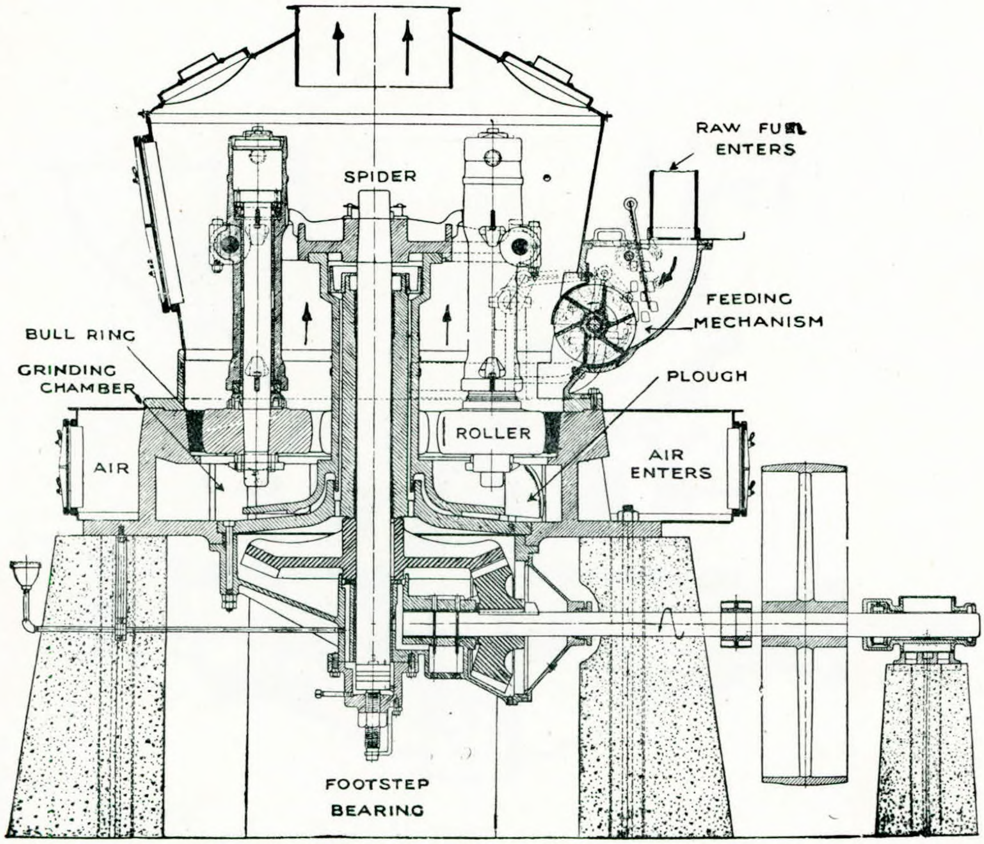


FIG. 10.—Raymond mill.

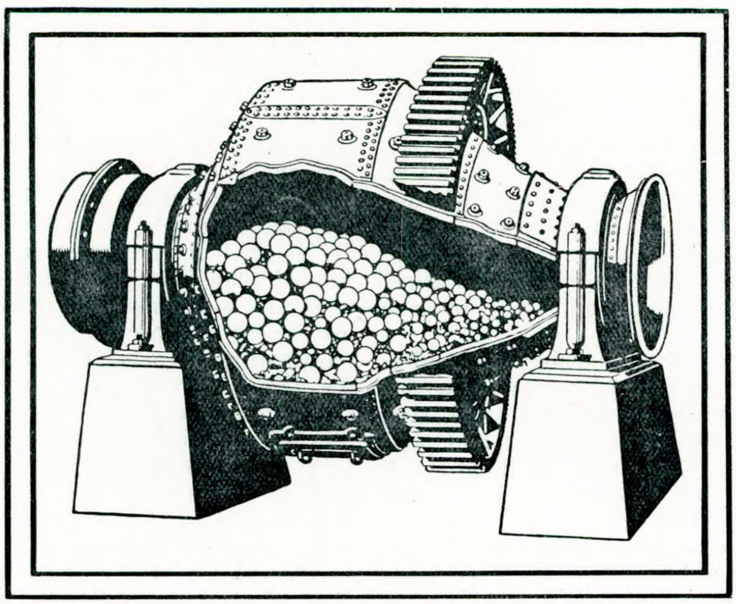


FIG. 11.—Hardinge mill.

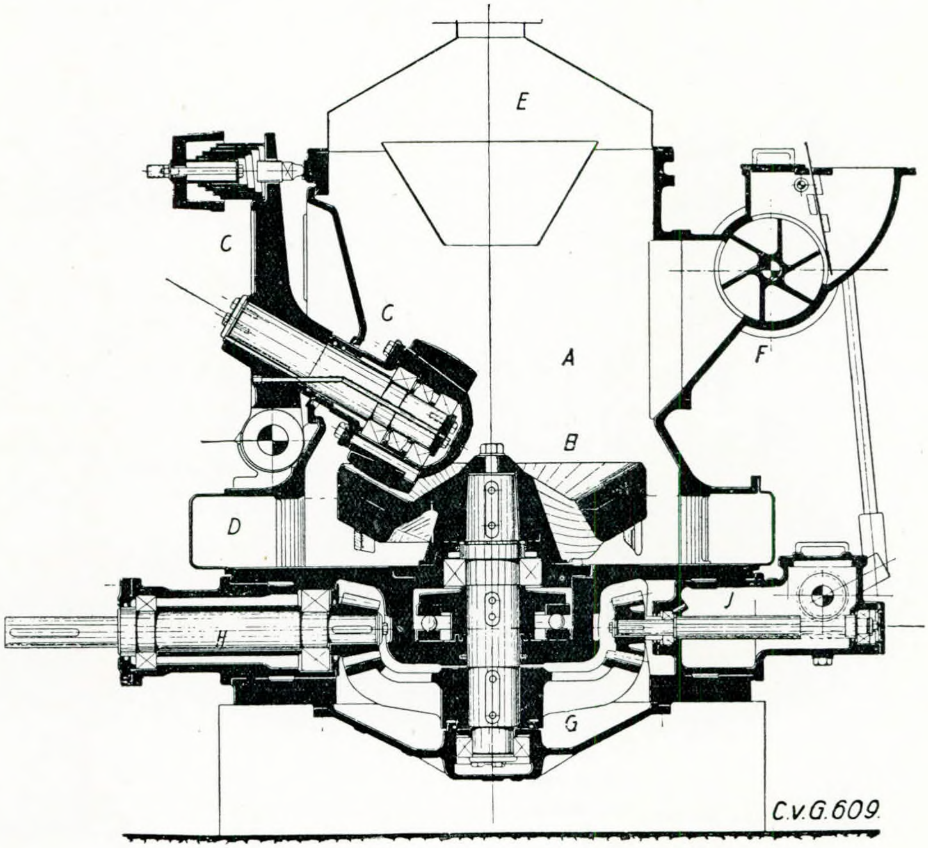


FIG. 12.—Latest type of Lopulco mill.

The new mill which is being installed at the Brimsdown extension of the North Metropolitan Electric Supply Company is of the Lopulco type. It is illustrated in Fig. 12 and consists of a rotating table or grinding ring upon which the rollers bear. The rollers rotate on stationary shafts which are spring supported. The spring may be adjusted whilst in operation, and the roller may be withdrawn from the grinding ring without interfering with the mill operation. A differential speed between the ring and rollers is obtained by suitably designing the slope of the rollers and grinding table. This assures even wear on all parts. Coals containing 15 per cent. moisture can be easily dealt with. Lubrication is by an automatic oil pump, and no internal lubrication is required.

For cylindrical or conical-shaped ball mills exact relations have been worked out to show the effects of different types of lining, ball sizes, size and class of material, etc., on the output and performance of the mill. These relations hold good in practice, and it is now possible to predict the performance of mills very accurately. For the purpose of the paper it is proposed to omit these calculations as they would occupy a very considerable amount of space, and in addition, are of academic interest only. Generally speaking, cascading of balls occurs if the mill speed is above or below a certain value. Changes in ball sizes and ball weight produce variations in output. Linings of mills should be rough, and preferably shaped as lifters which may be a series of arcs of small radius. Smooth linings allow balls and material to slip. If the lifters are too high cascading results, and also increased ball and liner wear is entailed. The best results will always be secured if the sizes of the balls are such that the largest is capable of just breaking the largest piece of material. In order to allow for wear, this size should be increased by say ¼in. in radius. If larger balls are used more force will be expended than is really necessary, and if too small balls are used energy is wasted because they are insufficient to break the largest pieces. Power requirements depend, therefore, to some extent on the use of correct sized balls, and the feeding of suitably sized coal.

Having given a very rough summary of the four principal mills and the general considerations affecting their use, a few notes on general mill troubles and the major developments in mill design may be of interest.

Developments in mill design seem to be directed along the following lines :—

(1) Research on better and more suitable

quality materials for all parts so as to reduce maintenance costs.

(2) General refinements of details of mill construction on the results of past experience.

(3) Increased use of pressure lubricating systems.

(4) Design of mills specially to incorporate drying arrangements, and suitable for high temperatures.

Drying has been discussed elsewhere, and as far as mills themselves are concerned it may be necessary in the future to secure immunity from the effects of much higher temperatures than those now in general use.

Regarding metallurgical research, the principal parts to which attention is being given are linings, bull rings, rollers or hammers, and balls. Experiments on the chromium-plating of parts have been conducted in America, but have produced results of insufficient merit to warrant further adoption of this process. Chrome and manganese steels are obtaining increasing application. Electric welding of worn parts, and re-machining is being adopted with success. Such parts as bull-rings, pendulums and spiders are being treated in this manner. In some installations experience indicates that it is better to replace rollers by new ones, whereas in others the roller is given an electric welded coat and machined. These rollers are reported to give excellent results. Both methods seem to have advantages. Bull rings have a life of 35-40,000 tons and rollers 18-20,000 tons. Coal feeders also require frequent attention, items such as turntables and ratchets in some installations requiring replacements after 6 to 9 months' service. No doubt in these installations the ash content is high and it would be profitable to investigate the coal quality in these cases. Where pyrites and tramp iron are present, it is essential to provide magnetic separators or other means of separation before introducing the coal into certain types of mill. The Lopulco type has provision for automatic separation. Chilled iron balls (Elverite) are being used instead of ordinary steel balls, and the life of these balls is reported to be 3-4 times that of steel. Forged steel balls are also being tried. In roller or similar type mills as roller wear increases the power requirements are increased, and mill capacity is decreased. It is, therefore, advisable to keep a careful watch on all components, for by timely replacements of components considerable savings may be gained.

The importance of the fineness of the mill product is now being gradually recognised, and it is indeed worthy of more searching investigation. The development of mills should be such that due recognition is given to this important consideration, and it would appear that very little extra cost would be necessitated. The thought and time expended on research would be amply repaid by the less frequent renewals of parts and the increase of availability. The overall cost of milling may be eventually reduced to about 3d. per ton of fuel milled.

Pressure lubricating systems are being more extensively adopted. Raymond mills do not lend themselves to the complete adoption of this method owing to the use of suspended pendulums. It is essential to amply lubricate the footstep bearing of this machine owing to the great load it has to carry. Pressure lubrication is advantageous for this purpose. New devices for the reception of grease for pendulum lubrication are being produced, and in a number of cases considerable improvement in operation results, coupled with greater economy of lubricant. Mixtures of turbine oil and lubricating grease are being tried with success, and are obtaining increasing favour. Mills which do not require internal lubrication are to be preferred. Pumps may be driven separately or from the main pulveriser. It is necessary to provide ample settling chambers and suitable filters to ensure that particles of pulverised coal are not carried back to the bearings. Ball bearings are being increasingly used, their reliability is fully assured, and the power consumption is thereby decreased. Generally, pressure lubricating systems fully repay their cost in the power that is saved, and in the decrease of maintenance costs.

Vibration in any machinery is objectionable, and pulverising plant is no exception to this rule. Elimination of as much vibration as possible should be the object of every designer. Too little attention has been paid to this desideratum.

New devices, continued ingenuity and advancing mill capacity suggest that there is as yet no finality in mill design nor any possibility of standardisation. Mill availability factor continues to increase and is now in the region of 90 per cent. Given proper care and attention to past experience and to prospective operating conditions there seems no reason why this factor should not be increased. Maintenance costs and operating costs are on the decline, and there is a tendency towards the simplification of construction, and as a result skilled labour costs for maintenance are avoided.

Powdered Fuel Bunkers (Central System).

Spontaneous combustion is frequently obtained in bunkers and therefore adequate venting arrangements should be provided, with dampers for use when fresh supplies are being added. Condensation should be guarded against by suitably insulating the bunker and, if necessary, by circulation of warm air or warm flue gas and air through the bunker. This enables the freed moisture vapour to be drawn off. In the event of fire, extinction should be secured by means of one of the forms of liquid CO_2 extinguishers, water having no effect upon such an impalpable dust.

Frequent clearing of the bunkers is recommended, not only to clear the fuel which is liable to condensation and spontaneous combustion, but to remove caked material from the bunker sides. If a boiler is to be taken out of service for a long period the bunker should be first of all emptied.

In the design of bunkers the slope of the sides should not be less than 60° to the horizontal. Ribs or other members such as bunker ties should be avoided as these restrict the flow of coal. Bunkers should be lined with concrete to prevent erosion and corrosion.

Piping.

The actual arrangement of mill piping is of course dependent on the layout of the plant. In general, all layouts are similar, and there is no necessity for a special description of a given installation.

The life of piping seems to vary a great deal and it is no doubt greatly influenced by the characteristics of the fuel handled. In some installations holes develop after only a year's service, whereas in

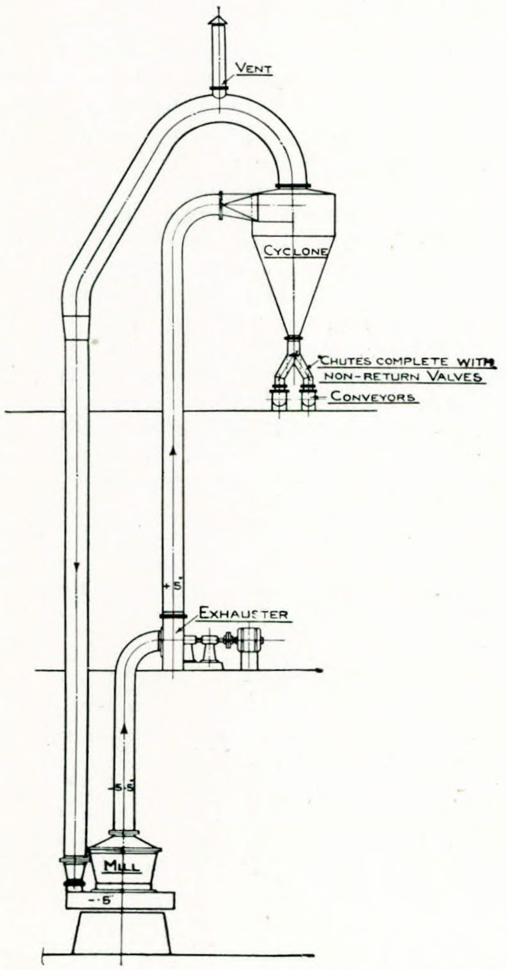


FIG. 13.—Obsolete method of mill piping for central systems.

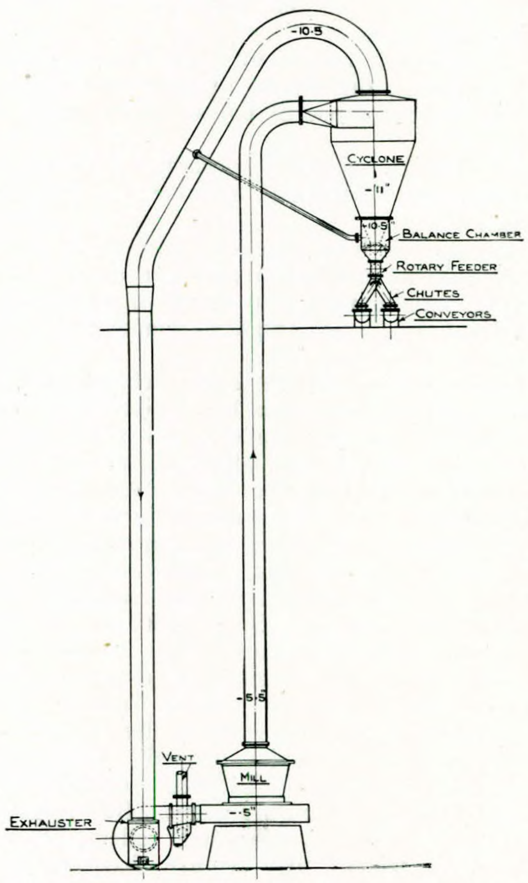


FIG. 14.—New method of mill piping for central systems.

others satisfactory wear for five or six years has been given. The life is to some extent dependent upon the layout, for wherever a change of direction is given to the fuel mixture appreciably more erosion occurs. The new method of mill piping to obviate exhauster wear is compared with the old method in Figs. 13 and 14. Attention to this factor should be given in the design stage, and if necessary, the piping at such points should be suitably reinforced. Where holes develop electric welding is perhaps the only satisfactory method of repair, but eventually, after frequent patches, the pipe will not withstand this treatment any longer and has to be replaced. Cyclones are affected very severely, especially at the lower parts where the friction is the greatest. These parts should be strengthened by the provision of thicker plates in their construction and the provision of a concrete lining. Rubber lining for conveyor piping has been tried, but up to the present time the results cannot be considered as indicating an extension of its use.

Exhausters.

Exhauster blades vary very greatly in their life, and results of 3,000 to 40,000 tons of fuel handled are available. Chromium plating of exhauster blades has been tried, but information on this process shows it to be economically unsound. The use of manganese and chromium steels is meeting with wider favour for this purpose. For repairs, electric welding has secured widest adoption. New blades may have a superimposed electric welded coating in accordance with their known streamline characteristics before being put into service.

Burners.

There are so many types of burners on the market that description of them is impossible and to select burners for this purpose might be invidious.

Considerable diversity of opinion on their design exists, but this may be attributed to experiences of varying operating conditions and the conduct of investigations along different lines of development. Early forms of burners were designed to produce delayed combustion in order to ensure refractory protection, but to-day the advantages of turbulent furnace conditions are universally recognised, and with the advances in the use of preheated air and bare tube walls the object is to stimulate combustion as much as possible. Combustion delay was accomplished by two methods, these being the avoidance of turbulence and by limiting the primary air supply to the burner, the balance of the furnace air being admitted as secondary air. Efficient combustion could not, therefore, be achieved.

To ensure a high degree of vitiation of the mixture immediately it enters the furnace, helical or spiral grooves are incorporated in the burner casing, vanes of various designs are employed and deflecting impellers are used. Air may be admitted through a central tube and suitably dispersed to produce the necessary agitation of the mixture. Burners may be mounted in various positions in the furnace, of which it may be sufficient to mention the successful tangential method in which the location of the burners is at the corners of the furnace, as shown in Fig. 17, p. 28.

The essential characteristics of burner design are accessibility, adjustability, maximum mixture dispersion, easy and cheap renewal of parts, and immunity from the effects of high temperatures. It is along these lines that development is proceeding and a number of burners fairly satisfactorily meet this specification.

Sampling of Pulverised Fuel.

In both systems of firing it is easy to arrange for the sampling of the fuel for purposes of obtaining the calorific value before entry into the mills. In the central system an objection to this course exists for it is evident that there may be an appreciable time between pulverising and combustion owing to the interposition of the storage bunker. It is therefore necessary, in the interests of accuracy to sample the fuel from the feeders. The actual method of sampling is dependent upon the layout of the plant. Large air-tight containers should be provided for the reception and storage of the samples, for as has been explained, powdered fuel is extremely hygroscopic, and delays in sealing the storage vessel may lead to appreciable errors in the final analysis. For smaller samples, air-tight containers of various sizes are useful.

For determinations of moisture content, the mill entrance should be the sampling point, but if it is required to obtain the moisture content as fired, the pipe leading to the burner should be chosen. To determine the amount of drying obtained the coal entering the mill and the coal being fed to the burners should be sampled. In the central system the mill exit, or a point located near the mill exit should be chosen as the second sampling point in a drying test.

Collection of samples of pulverised fuel for fineness determination should be at points as far away from a bend as possible, and preferably in a downstream of coal. This obviates eddying and a better sample is obtained. In order to obtain comparative samples for a large number of tests the pressures in the pipe on each occasion should be identical to ensure consistent sampling. In some cases, tests are made in different positions in the pipe and the weighted average of these is taken. Where hot primary air is used, say up to 350° F. it may be advisable to lower the air temperature while the sample is being obtained. For these tests suitable holes should be drilled, and screwed plugs inserted when not in use.

Various means for entrapping the coal are employed. These may take the form of a bag mounted over the end of a small tube the other end of which is spoon-shaped. A vacuum sweeper bag attached to a length of pipe is used in other cases. In any case, whichever method is used, the pipe should be sufficiently long and free to sweep the whole cross section of the fuel pipe to enable a representative sample to be obtained.

The Selection of Coals.

The general experience of all pulverised fuel users has shown that economical and practical success greatly depends on the class of coal chosen. In Great Britain, coals are very inconsistent in quality and even if the use of a given class of coal is decided upon, there is no guarantee that its quality will be maintained, so that the problem is greatly accentuated.

Coal should be preferably bought on a calorific value basis rather than by weight of material or on the lowest cost per ton. This proposal is not new, it has been advanced on a number of occasions, but it has not obtained wide acceptance. Many difficulties are present, but these could be overcome and the fact still remains that the purchase of heat is more logical than the purchase of material, which might be anything.

Where the cost of several almost identical coals is similar, the one with the highest calorific value should be selected for reasons of generally superior combustion characteristics, lower ash content and the economy of electrical power owing to the smaller quantity to be handled. Where suspicion exists as to the actual ash content, it can be allayed by subjecting samples to a proximate analysis. Anthracite is more difficult to burn than bituminous coals on account of its lower volatile content, but its calorific value is high. The efficiencies and outputs of boilers using this class of coal are lowered. It has been shown elsewhere that high volatile bituminous coals are quite suitable for powdered fuel firing due to their superior combustion qualities, but in addition they cost less to grind. Mill capacity is thus increased with an accompanying reduction in operating cost. Anthracites are very abrasive and increase mill maintenance costs, but if it is desired to use them, this can be done by judicious mixing with bituminous coal. Four examples of fuels and comments upon them are given in Table 2.

TABLE 2.

TYPICAL EXAMPLES OF COALS SUITABLE FOR PULVERISED FUEL FIRING.

	(a)	(b)	(c)	(d)
Moisture (a) surface %	6·47	2·46	5·34	2·83
(b) hygroscopic % ...	6·52	3·46	4·10	1·02
Total %	12·99	5·92	9·44	3·85
Calorific value (as dried) B.T.U.'s ...	13,290	13,100	11,760	13,590
Calorific value (gross as fired)	11,570	12,380	10,650	13,050
Proximate Analysis.				
Volatiles % ...	38·00	37·50	34·50	35·65
Ash %	4·30	8·50	15·08	4·95
Fixed carbon % ...	57·70	54·00	50·42	59·40
Price per ton ...	23/-	23/-	18/4	24/3
Value factor ...	93,950	100,150	106,700	104,600

NOTE.—The value factor is the number of B.T.U.'s per penny.

The first coal was tested during wet weather and as a consequence the moisture content was fairly high. The quantity present is not difficult to remove when flue gas drying is used. The second coal, although it possesses a higher value factor, contains a greater percentage of ash. It is nevertheless, a very good coal on account of its high volatile content and would be an economical coal to use. The third fuel is of medium quality, but it is quite suitable for pulverised fuel firing, its volatile matter being sufficiently high and its value factor is such that it would partially compensate for the probable additional expense of slag removal. The last coal is a very suitable one.

The presence of ash has a considerable effect on the production cost of steam, and being extremely abrasive matter it exerts its influence on the maintenance cost of mills, piping, etc. Increased ash content results in furnaces having to deal with greater quantities of slag and the attendant risk of choking of the boiler gas passes, the boiler availability thereby being lowered. Where refractories are used, their life is appreciably shortened.

In the early days of pulverised fuel firing in Great Britain, attempts were made to realise the claims of the principal powdered fuel exponents, especially with reference to the use of mediocre fuels. These claims were largely based on American experience, but the classes of coals which were experimented with were such that the successful American experience was not repeated in this country. Reference to Table 3 makes this clear.

TABLE 3.

BRITISH AND AMERICAN ASH CONTENT COMPARISONS.

Boiler 80,000lb. per hour. *Total heat in steam* 1,350 B.T.U.'s. Boiler efficiency the same in both cases.

	American conditions.	*British conditions.*
Coal B.T.U.'s	14,000	10,400
Ash %	2·0	16·38
Lb. Coal per hr.	9,150	12,450
Lb. Ash per hr.	184	2,100

Ratio of ash quantity 11·50

Ratio of ash contents 8·19

The 10,400 B.T.U. coal is a common slack, and from the quantities of ash to be disposed of, it will be appreciated that it is desirable to minimise the use of such classes of coal. The effective mill capacity is reduced, boilers are restricted in overload capacity and maintenance and renewal charges are increased.

One of the advantages claimed for pulverised fuel is the ability to deal with low-grade fuels. There are many who contest this claim on the ground that it is not substantiated in practice, because the use of such fuels is disadvantageous and cannot be continued indefinitely. While this is perfectly true, it does not seem reasonable nor rational to operate boilers on these fuels and expect best performance, especially when more economical grades are available. The advantage of pulverised fuel really lies in the ability to consume such fuels in the event of emergency. In other forms of firing the consumption of these fuels is impossible. It may be noted here that there has been a tendency for these low-grade fuels to rise in price with the increasing demand. If this tendency continues, it will become uneconomic to continue their purchase.

The amount of slagging in a furnace is dependent upon the ash fusion temperature, in addition to the volume of ash dealt with. This temperature is extremely variable, and tests on samples of a given coal have produced variations of 5 to 10 per cent. A table of ash analyses and the corresponding ash fusion points is given in Table 4.

TABLE 4.
ANALYSIS OF PULVERISED FUEL FLUE DUST.

	(a)	(b)	(c)
Fusing point °F.	2,100°	1,750°	2,350°
	%	%	%
Silica (S_2O_2)	45·80	44·52	46·10
Aluminium oxide (Al_2O_3) ...	24·50	18·64	16·20
Iron oxide (Fe_2O_3)	14·20	31·35	30·40
Calcium oxide (CaO)	2·30	1·33	2·20
Magnesium oxide (MgO) ...	0·80	1·10	1·00
Sulphur trioxide (SO_3)	0·90	1·80	1·20
Phosphorous pentoxide (P_2O_5) ...	0·20	0·25	0·10
Titanium oxide (TiO_2)	—	0·76	—
Combustible in ash	9·60	0·25	2·20
Undetermined	1·00	—	0·60

The analysis of the coal producing slag under (*b*) had the following constituents: Volatile 34·66 per cent., ash 12·05 per cent., carbon 53·9 per cent., sulphur 2·85 per cent.

From these analyses it will be observed that not only are there considerable variations of constituents, but in their fusion temperature. It is desirable to test each class of coal entering the station but preferably before purchase, and to select with due regard to other considerations those coals which appear to be the most consistent and possess the highest fusing temperature.

The best practical solution of the ash problem is perhaps that of coal washing or coal cleaning. Not only is it uneconomical to pay for the carriage and handling of ash, it is equally so to incur increased milling charges, etc. The cost per ton of material cleaned is in the neighbourhood of 6d. This figure cannot be considered excessive when 10 to 15 per cent. of ash is removed and its attendant troubles eliminated. Many coal cleaning methods are available and there seems to be a tendency towards more general acceptance of the economic advantages permitted by their use.

It is significant that it was not until recent years that much interest was taken in coal technique and yet coal was the raw material from which electricity was generated. The new aspect on this question is that of studious research in all fuel problems, and it is to be welcomed. The use of pulverised fuel has contributed in no small measure to this progress.

While on the subject of coal selection reference may be made to the tendency towards the classification of coals in accordance with their petrographic features. The technique of coal petrography is still in the development stage despite the great amount of research which has been conducted in this particular sphere. The principal distinguishing constituents of ordinary bituminous coals in accordance with petrographic classification are:—

Durain—the hardest portion of coal, being of firm granular constitution. It is dull in colour.

Vitrain—the soft bright portion of coal.

Clarian—medium bright portion of coal of fine banding.

Fusain—the easily powdered portion of coal being readily detachable and fibrous.

Various methods are available to secure separation of these constituents and each constituent may be utilised for a particular purpose. For pulverised fuel firing the fusain may be used. It will be sufficient to describe the characteristics of fusain very briefly. Fusain is relatively inert to oxidation and contains high pyrites, ash and sulphur contents, but being porous and powdery it lends itself to easy and economical pulverisation. To eliminate to some extent its disadvantages it must be suitably blended with smaller proportions of clarain and durain which have coking and swelling characteristics, as well as being rich in volatile matter. Coal cleaning and blending on a petrographic basis has been suggested as a solution of most of the carbonising problems with which industry is faced, and the blending to individual purchaser's requirements has been proposed.

Boiler Testing, Etc.

The pursuit of efficiency demands periodical boiler tests being conducted in any power station. Frequent checks should be kept on all items of plant. Mills should be tested for their output capacity and at the same time for fineness of pulverisation and the number of units per ton of auxiliary power required. As the last item depends upon the moisture content of the coal, due regard should be given it in the analysis of the test results. Drying tests should be frequently conducted and it is necessary to employ a judicious method of sampling the incoming and outgoing coal in order that the results may be comparative. The coal from each mill should be tested regularly once per week for fineness as a routine job. Ash content and ash fusion tests should also be routine work, the former being taken on the daily proximate analysis and the latter when consignments of new classes of coal are delivered, and also as a check on any observed irregularity in the boiler slagging conditions. An ultimate analysis of coal should be occasionally obtained, and continuous observation of the moisture content is advisable. Where dust-catching apparatus is in use, the efficiency of this plant should be constantly maintained, and testing of this equipment is thus important. Samples of slag and flue-dust may be occasionally subjected to an ultimate analysis, and this test should be associated with a similar analysis on the coal that was being burnt at the time of the slag production. This test is perhaps best left to an expert.

A keen watch should be kept on the boiler house auxiliaries electrical energy, and reasons for any wide variations investigated. Pulverising equipment, etc., should be preferably on independent circuits with independent metering.

When allowing for electrical auxiliary power on a boiler test, the number of B.T.U.'s to be debited against the boiler should be calculated from the overall station thermal efficiency figure.

In the arranging of these tests much depends on the layout, but it is hoped that sufficient has been said to indicate the general plan to be adopted.

Power Station Thermal Efficiency.

The efficiency of individual items of power station plant is continually increasing, and turbo-alternator units utilising high pressures, high temperatures, the regenerative cycle and good vacuum conditions have achieved overall thermal efficiencies of over 32 per cent. Similarly, works auxiliaries such as draught fans, motors, circulating water pumps, etc., show improved performances as a result of increasing size and better design, and this accompanied by simplification of power station design further reduces the heat consumption required to produce the electrical energy. Unfortunately, due to the high boiler pressures feed pump energy requirements show an increase, but this is to a small extent offset by an increase in the plant efficiency. In this march of development, it is pertinent to investigate the possibilities of pulverised fuel. Progress is towards the installation of larger turbo-alternator units and to concentrate a number of these large machines in one station, thus displacing the less efficient station. In the boiler house, the advance is towards the adoption of one boiler unit per generating unit, but up to the present time the turbine designer has succeeded in keeping ahead of the boiler designer. Taking the case of the 160,000 k.w. machine of the East River Station, New York, this requires approximately 1,700,000lb. of steam per hour, and the largest boiler in existence is only capable of generating 1,250,000lb., also at East River. Thus, the boiler designer is faced with a serious problem, but it is to the credit of the turbine designer that he has achieved considerable success not only in increasing the size of his machine, but in effecting a very considerable steam economy, at the same time thus assisting the boiler designer.

An estimate of the possible thermal efficiencies of a stoker-fired station and a powdered fuel station is given in Table 5. The comparison is made for a station using identical turbine terminal conditions and turbo-alternator sizes but with a boiler size of 500,000lb. per hour in the stoker fired case and 800,000lb. in the powdered fuel case, and using their maximum operating efficiencies. See Fig. 15.

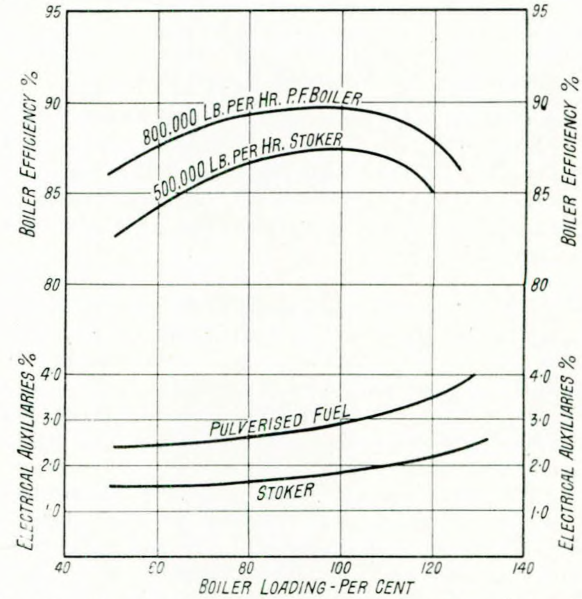


FIG. 15.—Powdered fuel and stoker-fired boiler efficiencies.

It will be observed that some slight adjustments for the individual efficiencies have been made. The boiler house auxiliaries have been corrected in each case by 1 per cent. to include other boiler house auxiliaries such as feed pumps. The throttle and radiation losses for the powdered fuel case have been adjusted to allow for the fact that the larger boilers will have a relatively smaller radiation and throttle loss, and similarly, the drip and drains and

TABLE 5.

COMPARISON OF STOKER-FIRED STATION AND PULVERISED FUEL STATION OPERATING EFFICIENCES.

Particulars of Boilers and Turbo-Alternators.

Size of Boilers (Stokers)	500,000lb. per hour.
„ „ „ (P. Fuel)	800,000lb. per hour.
„ „ Turbo-Alternator	75,000 k.w.
Steam Pressure (Abs.)	615lb. per sq. in.
„ Temperature (stop valve)	850°F.
Vacuum	28·5in.

	Stokers.		Pulverised Fuel.	
Individual Plant Efficiencies.	*Rankine Cycle.*	*Regenerative Cycle.*	*Rankine Cycle.*	*Regenerative Cycle.*
Boiler Efficiency	87·25	87·25	89·0	89·0
Boiler Auxiliaries	97·00	97·00	95·50	95·50
Turbine Efficiency	81·00	82·50	81·00	82·50
Feed Heater Efficiency	—	99·00	—	99·00
Alternator Efficiency	96·75	96·75	96·75	96·75
Throttle and Radiation Loss	97·00	97·00	97·50	97·50
Condenser Auxiliaries	97·00	—	97·00	—
Drips, Drains, Loss in Ashes	96·00	96·00	97·50	97·50
Operating Factor and Banking Losses	96·00	96·00	97·00	97·00
Bled Steam	12 per cent.		12 per cent.	
Station Thermal Efficiency. per cent.	24·63 per cent.		25·58 per cent.	
Coal Consumption (12,000 B.T.U. coal) lb. ...	1·152 lb. per k.w. hr.		1·111lb. per k.w. hr.	
Difference in Thermal Efficiency, per cent. ...	0·86 per cent.			
Difference in Coal Consumption, lb.	0·041lb.			

ash losses have been modified to include heat and combustible left in riddlings. As regards the operating factor, since another boiler would have to be brought into service for a load of 75,000 k.w. this factor has been adjusted accordingly. The steam required at this load would be about 800,000lb. per hour and it is considered advisable to point out that the boiler efficiency of the stoker-fired station would be perhaps 2 per cent. less than the efficiency given on account of the lower loading. There would also be a very small economy in the pulverised fuel boiler auxiliaries in the power required for fuel handling, but no account of this has been taken.

The pulverised fuel station would, in general, show a better average performance due to the flatter efficiency characteristic of the pulverised fuel boilers.

It will be interesting at this stage to compare the boiler house efficiencies of a pulverised fuel station and a travelling-grate station. Bruce has recently given data on the operating results of a large pulverised fuel plant in Great Britain and Messrs. Berry, Gaze and Verity gave the results of the operation of a modern chain grate boiler house some months ago. These have been brought up to date by the publication of more recent results. The two installations to which these results refer may be taken as being representative performances of well-maintained and efficiently-operated boiler houses, and as such, reliance may be placed in the data put forward.

OPERATION STATISTICS OF PULVERISED FUEL BOILER HOUSE FOR 1930.

(NOTE.—1931 figures are not yet available).

Total coal consumed for all purposes ...	292,088 tons
Total water evaporated	5,300,000lb.
Average steam pressure at boiler	380lb./sq. in.
Average steam temperature at superheaters	715° F.
Average feed water temperature at h.p. bled steam heaters	260° F.
Average calorific value of coal as fired	10,700 B.T.U.'S per lb. (gross)
Boiler plant thermal efficiency	88·8%

OPERATION STATISTICS OF TRAVELLING GRATE BOILER HOUSE FOR 1930 AND 1931.

	1930.	1931. (10 months only)
Total coal burnt, tons	144,901	121,946
Total coke burnt, tons	19,357	25,597
Fuel used for banking and lighting up, tons	2,957	2,318
Percentage fuel used for banking	1·80	1·57
Average gross calorific value at boilers (as fired) B.T.U.'s per lb.	11,232	11,034
Average steam pressure ...	378	379
Average steam temperature at boiler	769	768
Average water temperature at economiser	234	238
Boiler efficiency per cent. ...	82·37	82·482
Net running boiler efficiency less banking, per cent.	83·87	83·796

If account be taken of the electrical auxiliary power the thermal efficiency of the pulverised fuel boiler house and the chain grate boiler house may be assumed as approximately 85 per cent. and 80·5 per cent. respectively.

Flexibility of Pulverised Fuel Boilers.

Tests conducted by Messrs. P. Rosin, E. Rammler and H. Stimmel on the flexibility of powdered fuel boilers, and solid fuel boilers were undertaken at the request of the National Coal Council (Reichskohlenrat) of Germany and were made in order to ascertain the flexibility and adaptability of the boilers to changes of load. Three boilers were used :—

	Capacity.	Pressure.	Type.
(1)	300,000lb./hr.	380lb. per sq. in.	Humbolt
(2)	225,000lb./hr.	380lb. " " "	Band W.
(3)	200,000lb./hr.	380lb. " " "	Oschatz

These tests were made in order to determine the behaviour of the units under slow fire; starting at different loads the demand was raised to a maximum and the speed of response determined. Similarly, load was reduced to various partial loadings. The final tests on response to demand, and at frequent intervals during the response observations were made on quantity of steam generated, its pressure and temperature, volume of feed water supplied and water level. These data were plotted against time and the rapidity of response to a change in demand expressed as a "flexibility coefficient" given by the increase in output per minute as a percentage of the maximum output.

From lighting up the first burner in the case of the 300,000 lb./hr. boiler full steam pressure was obtained in 2¼ hours, and one hour later the boiler was generating at the maximum rate. The Babcock and Wilcox boiler developed full pressure in 1 hour 55 mins. and 20 mins. later was at its maximum load. On 75,000lb. boilers with which the author was acquainted, full steam pressure has been generated in 50-55 mins. and 7-10 mins. later full output was being delivered. Unfortunately, the author has not performed any similar tests himself but he can affirm very creditable results being obtained under emergency conditions, such as system disturbance, on pulverised fuel boilers.

The authors of the above tests have concluded that with respect to quickness of adaptation to fluctuating demand the mechanical grate gives flexibility equal to pulverised fuel, but while giving due prominence to this statement the present author does not associate himself with their views. With regard to picking up load the chain grate boiler possesses the advantage that it has a large bed of incandescent fuel stored on the grate which can be of great service in an emergency, but for the control of boiler output when a station has suddenly dropped load this is disadvantageous. Even stoppage of the grate, and the shutting down of all draught plant is sometimes insufficient to prevent boilers blowing off. This disadvantage is not present in pulverised fuel installations.

Further examples of what can be achieved in the flexibility of pulverised fuel boilers are given in Table 6.

TABLE 6.

LIGHTING UP TIMES OF DIFFERENT SIZES OF BOILER UNITS.

Size of Boiler.	Lighting Up Time.	Remarks.
220,000lb./hr.	70 mins.	Put on 130,000lb. load 5 mins. afterwards.
200,000lb./hr.	70 ,,	Went up to ¾ output 2 mins. afterwards.
160,000lb./hr.	50 ,,	75,000lb. 2 mins. afterwards.
180,000lb./hr.	60 ,,	Full load 3 mins. afterwards.
100,000lb./hr.	45 ,,	Full load 1¼ mins. afterwards.

The lighting up time is the time required to bring the boiler up to full boiler pressure from cold.

It is important to make adequate provision for drainage of the steam line in order to achieve such good performance. To light up boilers regularly with such rapidity is not recommended.

Pulverised fuel plant is extremely flexible in operation especially when good classes of coals are being used. Further, it enables the use of a wide range of fuels because with this form of firing they are capable of being burnt. This is another form of flexibility which has inestimable advantages especially in the time of a national coal crisis. Unimportant as this point might seem it is one that should be borne in mind. With further experience in the grinding and drying of the raw material there is no doubt that pulverised fuel will assert its superiority over other forms of firing, if it has not already done so. Thus, in regard to flexibility considerations, pulverised fuel plant fulfils all the desiderata of modern generating stations and in doing so, it definitely establishes itself as the best form of stand-by plant.

As is well known, the central system offers better steam pressure regulation than the direct-fired system. To utilise the advantages of low capital cost of the latter system, and without seriously increasing it to combine the advantage of the central system, the following simple proposal is put forward. A central powdered fuel bunker fed by say, two mills, one being a stand-by, would supply an auxiliary burner to each boiler installed. The capacity of the bunker would be as a suggestion, 100 tons for a station of say 300,000 k.w. capacity. The auxiliary burner would be automatically controlled and it would deal with the small variations of pressure up to say 5lb. Major variations would be taken on the main pulverisers.

The result of variation of steam pressure and temperature on turbine efficiency is well understood, and it is regrettable to state that sufficient attention is not paid to correct control of these two conditions in many power stations. A variation of steam pressure is usually accompanied by a variation of steam temperature and thus the usual effect on turbine efficiency is twofold. It is sufficient to add, that not only does proper control of these two factors aid power station and system operation but it results in economy. As the pulverised fuel method will produce these results more easily, there is thus some incentive to its adoption.

Banking Losses.

A feature of great importance in powdered fuel stations is the entire elimination of banking losses. Even in the best stoker-fired stations with strict control of these losses, they may reach values of 1·5 to 4·5 per cent. of the total requirements. If the station is of large capacity, the amount of coal lost in banking assumes considerable magnitude, and any method to reduce it is welcome.

It is true that heat is lost in lighting up and shutting down of pulverised fuel boilers; this is common to any form of firing, but even under lighting-up conditions the author would incline to the view that pulverised fuel offers a slight economy due to the good combustion conditions which usually obtain shortly after the boiler is lit. On lighting up the author has seen the CO_2 recorders of a number of stations showing 8 to 10 per cent. only a short period after the ignition of the fuel.

To determine the banking loss over a given period, tests or checks can be made on the actual weighed coal delivered to the boilers, or the station Parsons line can be employed. If the latter method is used it is significant that stations using powdered fuel always show generally better performance than the stoker-fired stations.

When boilers are not required for load but pressure must be maintained, an occasional " flash " up to full pressure is sufficient to keep them in readiness for service.

Unburnt Carbon in Ash.

Generally speaking, the amount of unburnt carbon remaining in the ash discharged from pulverised fuel installations is lower than on stoker equipment. This is no doubt due to the high CO_2 which is and can be maintained, thus indicating more complete combustion.

Average values of a large number of test results show the carbon remaining in the "fly ash" to vary between 4 per cent. and 45 per cent., these figures corresponding to 0·2 per cent. and 2·9 per cent. of the total carbon.

The value depends to a great extent upon the pulverising efficiency and the CO_2 at which the boiler is operated. It depends to some extent upon the turbulence which is maintained in the furnace and also upon the ash fusion temperature, for if this is low, considerable quantities of unburnt carbon may coalesce with the molten material. It is, therefore, desirable to operate boilers according to these considerations.

Experience of the North Metropolitan Electric Power Supply Co.

This Company has experimented for a number of years in various types of equipment for burning pulverised fuel. The pulverised fuel plant installed in the stations of this Company is as follows :—

		Type.	No.	Size.
Brimsdown	...	Central	5	100-120,000lb./hr.
		Direct	4	175-200,000lb./hr.
Willesden	...	Direct	2	75-90,000lb./hr.
		Central	1	80-100,000lb./hr.
Brimsdown (old station).	...	Direct	2	9,000lb./hr.

Total boiler capacity (on lower rating) 1,448,000lb./hr.

The output particulars for this Company for the period covered by the last Electricity Commissioner's Return of Authorised Undertakers' generating stations are averaged as follows :—

No. of units generated	...	236,567,725
Maximum load	...	95,350 k.w.
Load factor of system ...	...	28·30%
Thermal efficiency ...	...	18·5%

This performance may be considered very creditable in view of the arduous load conditions of the system, and in addition a number of low output chain-grate stokers are used at two stations, thereby considerably increasing the banking losses.

Experience with coal drying apparatus has resulted in discarding three different types of dryers which were unsatisfactory. Systems were evolved to dry the coal by hot air or flue gas. This latter system has now been installed in all stations. At Brimsdown a small furnace was used to provide flue-gas for drying, and this arrangement worked with complete success. The single kiln has been replaced by three small kilns, one for each mill. Flue-gas drying is used on two boilers at Willesden, and hot-air drying is used on the other.

Vents from the mill circuit are dealt with by means of Visco-Beth filters which are of the sleeve type with special scavenging arrangements. They have given complete satisfaction up to date.

The pulverising mills in use at Brimsdown are of the Raymond type having a capacity of 12 tons. One Raymond 6 ton mill is used at Willesden, and four Fuller-Bonnot mills are used at the same station. In the new extension at Brimsdown Lopulco 6·3 ton mills are being used for the new direct-fired boilers, giving a total of 8 pulverisers for the new section. At Brimsdown, the pendulums occasionally seized, and specially oil-lubricated pendulums were introduced resulting in quieter running and a reduction of the amount of lubricant used. The Willesden pulverisers have given satisfaction, the only trouble experienced being hot gear-boxes, coal feeder turntables wearing smooth and the occasional ignition of coal in the mill due to hot flue-gas drying. The gear box trouble was transient and is not now experienced. At Brimsdown on the 120,000lb. per hour boilers at the back of the furnace wall, is a radiant heat superheater and the side walls are composed of fin tubes, except near the burners where there are double-spaced tubes. The front wall of the furnace is hollow and contains air ports through which pre-heated air is introduced into the furnace. A water screen is used, and the burners are of the ordinary fish tail type. These boilers are illustrated in Fig. 16.

Difficulty in obtaining complete combustion was experienced and this appeared to be due to incomplete mixture of fuel and air in the burners and the lack of turbulence in the furnace. Experiments and several changes of burners have produced finally successful results. At the Willesden station on a similar type of boiler, a new type of burner was introduced with satisfactory results and a new burner with improved control was also applied to the direct-fired boilers producing a considerable improvement.

Dust emission in two stations has necessitated the installation of special plant to deal with this problem. Two types of equipment are being used. In one case a Lodge-Cottrell electrical precipitator has been installed. Briefly, this consists of two large chambers in the flue in which the gas velocity is reduced. Plates of sheet metal suspended above each other on suitable supports make up a unit, the units being hung in rows along the full length of the chambers. A uni-directional current potential of 50-60,000 volts is applied to certain rows, the others being earthed. This current is supplied from a special transformer and rectifying equipment. Across the air gap between the plates an electric field is produced, and the dust particles are charged or ionised with the result that they adhere to the plates. A tapping arrangement consisting of an electric motor operating hammers provides occasional blows to rods running the full length of the chamber upon which the plates are suspended, the dust being shaken off into hoppers below. Dust collection is, therefore, obtained by dual action, viz., by precipitation and by reduction of gas velocity. The location of the precipitator is on the pressure side of the induced draught fan. In the base of the chimney water spraying was employed, but the sprays became choked with extremely fine flue dust and their use was discontinued. The efficiency of the complete arrangement is about 70-80 per cent.

In another station water washing arrangements were formerly employed. These were fairly effective, but much depended upon the correct disposition of sprays to prevent them choking. The present arrangement consists of improved spray chambers in the base of the stacks which intercept the dust resulting in the formation of a thin slurry. The effluent is pumped to two "Rovac" filters.

This filter consists of a drum rotating slowly in a tank, the sludge being delivered to this tank by slurry pumps. On the drum periphery, perforated plates and filter cloths are mounted, the drums being divided internally into a number of cells. As it rotates the cells are arranged for connection to a special vacuum supply, the solids in the slurry being built up on the filter cloth in the form of a cake, while the liquor is drawn through the cake and filter cloth and delivered to a vacuum

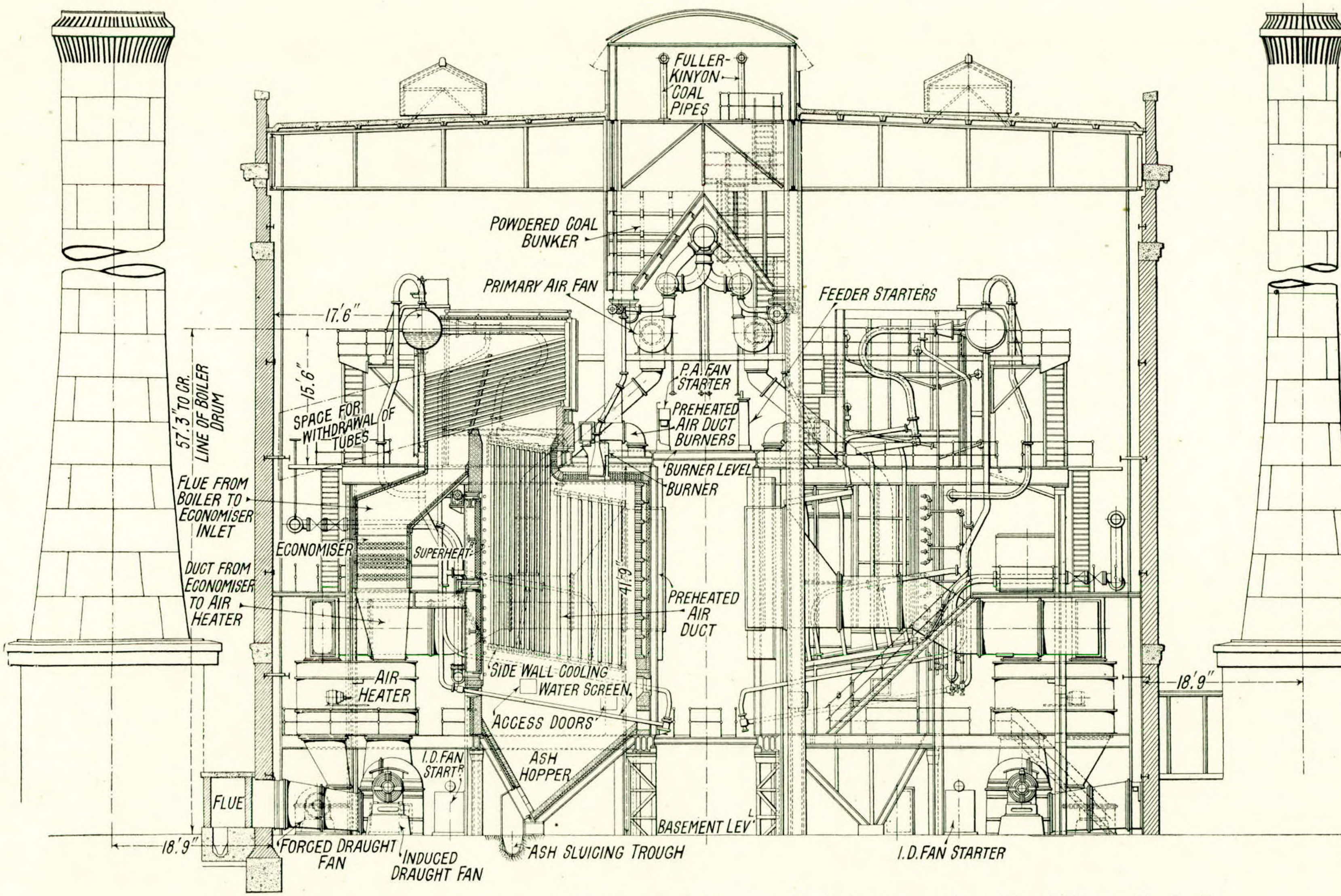


Fig. 16.—First section of Boiler House at the Brimsdown Station of the North Metropolitan Electric Power Supply Co. Evaporation 100,000lb. per hr. (normal economic rating).

receiver tank from which it is discharged by a filtrate pump. On further rotation of the drum, the cells being still connected to the vacuum plant, drying of the cake is continued, and as the drum revolves further it is brought into contact with a scraper knife, the cake being scraped away in a slightly moist state. Up to the present, this apparatus has worked with satisfaction, but difficulty is being experienced with the filter cloths which quickly rot owing to the alkaline nature of the slurry.

The clear effluent is used in the sprays of the spray chamber. These chambers are also fitted with a water curtain (supplied with the thin slurry from the original ash sump) which is used in emergency when the "Rovac"filters are out of commission. One boiler is fitted with a special "Keith-Blackman" grit-catching fan and pneumatic dust extraction plant.

The arrangement to be used on the Brimsdown extensions is firstly, dry grit catching by "Pneuconex" grit catchers located on the inlet side of the induced draught fan, followed by wet grit catching on the outlet side of the fan by means of sprays located in the spray chambers.

The "Pneuconex" system comprises a large circular chamber to which the flue gases are admitted at the bottom and immediately encounter a dense initial saturation mist across the complete section of the duct and produced by a series of sprays. Above the sprays a louvred disintegrating baffle communicates with a second chamber and in passing it suspended grit is deposited and ultimately washed away by the flow of water from the second series of jets. A further louvred baffle is placed above the second series of jets and above it again on the top of the enclosing vessel a few nozzles are provided which are normally worked periodically to wash down the upper baffle and clear the whole plant. The slurry is thickened in "Hardinge Thickeners" before being passed to the "Rovac" filters.

In the thickener which is of the rotary type, the solids in the effluent settle out in a tank at the bottom of which is a porous filter or percolating bed. The clear liquid is discharged through an overflow at the rim of the tank and also from a pipe connected to the bottom of the filter bed. The overflow and filtrate pipes are joined together outside the tank, the dewatered sludge being drawn off and delivered to the filter. the clear effluent from which is used in the spray chambers. The whole of this plant can be by-passed if required.

It will be noted that the primary and secondary grit-catching equipment has been designed as an integral part of the boiler unit and the induced draught fans have been placed on the outlet side of the grit catching equipment. This has been aimed at in many designs and the Company have made a really serious contribution to this sphere of engineering. So soon as greater efficiency in dust collection is achieved, so soon will be the elimination of fan and stack erosion problems and the avoidance of public nuisance achieved.

In the present form of plant the discharge from the stack is in the form of a slight white-grey haze. With the new form it is hoped that no discharge will be observed.

Another problem is in the disposal of flue dust. It has generally to be removed at the expense of the undertaker, whereas, in the case of stokers a ready market exists for the sale of the ashes. There is at the moment a moderate demand for dry grit of uniform grading which is used as a "filler" for bitumastic and rubber compounds, etc.

In dealing with the widely varying loads experienced on this Company's system and on occasions of system disturbance the flexibility of powdered fuel boilers has been very fully demonstrated and the absence of this characteristic might have produced serious results.

The Company is now engaged upon a 50,000 k.w. extension of the Brimsdown station and this will be accompanied by the installation of four new boilers of 175,000/200,000lb. per hour on the direct-fired system.

Dust and Sulphur Emissions.

One of the obligations of owners of electric generating stations is under the " nuisance clause " incorporated in their Electric Power Act. The duty is thereby imposed that all reasonable precautions shall be taken to eliminate nuisances such as smoke, fumes, etc. Since the recent erection of several large generating stations in Great Britain, especially in the Metropolis, much public attention has been focussed on the air pollution problem with the result that steps have been taken towards the elimination of the nuisance. Great Britain is not alone in these researches for the matter is being dealt with in other countries, irrespective of the type of firing employed, and it is safe to say that the dust emission problem has been one of the retarding factors in the development of powdered fuel firing.

Considering that an average amount of 80 per cent. of 200 mesh coal passes to the furnace of a pulverised fuel boiler and that after combustion the dust particles are infinitely smaller, the problem presents great difficulty. In stoker-fired stations it is much simpler. It is now possible to state that effective means are in existence to capture the majority of these emissions. Experiments continue with unabated vigour, no doubt being maintained by force of public opinion.

Reference has been made elsewhere to the work of the North Metropolitan Electric Power Supply Company. Brief notes will now be given on the principal methods of dust collection.

The electrical prcipitator is perhaps the most effective solution but its initial expense seems to be the principal influence against its wider adoption. The major troubles of its operation are broken insulators, arcing in the settling chamber, frequent renewal of rectifying blades and to some extent erosion of the plates. Blades have been modified to permit the use of an easily replaced strip of special material. The provision of cooling and ventilation and improved designs of insulators lengthens the life of these components. Efficiencies of 95 per cent. are reported. Research continues in the development and cheapening of this type of plant.

Numerically, gas washing plants seem to be more popular and there are many variations in the design of this apparatus. In some instances the flue effluent is discharged into water sluices and thence into the river. In others, it is conveyed to the usual type of ash receiver and hauled out in a moist state by a grab and carted away. Soap-tri-sodium-phosphate and other mixtures are washed into the flue and it is stated from experience gained from these methods that the addition of a suitable agent is an essential characteristic to permit proper wetting of the dust particle. Various combinations of rotary and fixed sprays are in use, with and without baffling arrangements in the flues. Cyclones are extensively used, and these may be connected in series. At some stations the simple expedient of reducing the gas velocity is employed. The dust precipitation in this last method may only amount to about 15 per cent. or 20 per cent. of the total dust entering the stack.

In the tangential system of firing the fuel is given an intense gyratory motion since it is fed from the corners of the furnace. The heaviest ash particles are thus thrown to the sides of the chamber due to their greater momentum and fall to the furnace floor. The particles of lighter density are carried to the stack to be later dealt with by the ash collection plant. As the centre of the furnace is at a very high temperature the fusion and coalesence of a portion of the total number of particles may occur and these heavier bodies are projected to the chamber walls, on their way to which they may solidify. In this manner the firing conditions aid collection of dust in the furnace itself and the demand on the dust collection plant is relieved. It has been found that from 50 to 60 per cent. of the total ash may be collected in the furnace as a result of the use of this system. Fig. 17 shows the principles of this method of firing.

In general, the maintenance and operating costs of these types of apparatus are small, the principal troubles being erosion and corrosion due to sulphurous gases.

As regards the latter, tests have been conducted in America to determine the relative rates of corrosion in various metals. These included steel, galvanised steel, cast iron, lead, brass, aluminium, Monel metal and chromium-nickel alloys of varying proportions of the two metals. The best result was obtained on a sample of 24 per cent.

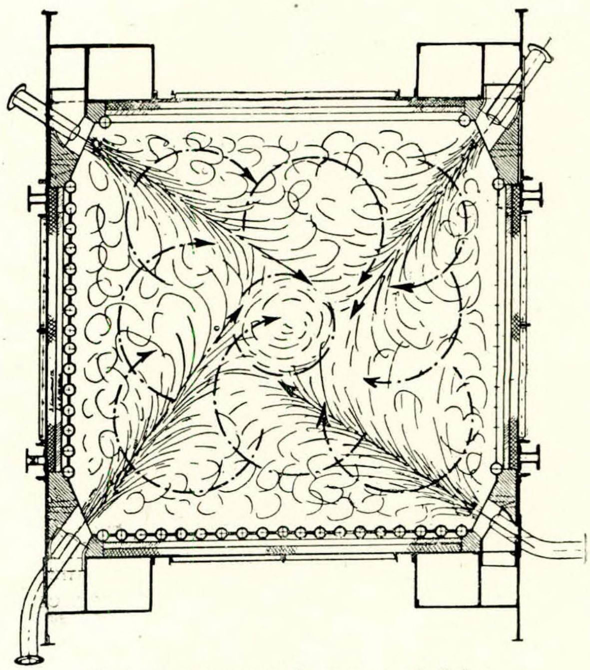


Fig. 17.—Tangential system of firing.

chromium, 12 per cent. nickel alloy, which gave the approximate rate of 0·3 grammes per sq. ft. per day.

Precipitator Testing; Sulphur.

To maintain satisfactory results, and as a check on operating performance, it may be necessary to conduct regular tests on precipitators in order to determine any falling off in efficiency. For the purpose of the test, the combustion chamber should be free from slag and this should be cleared before the commencement. A test on a precipitator may be made in the following manner :—

(1) After clearance of the combustion chamber, flues and precipitator, the test may be commenced.

(2) Samples of coal should be taken to determine the ash content. These should be taken every ¼ hr. from each weigher.

(3) All coal to the boiler should be weighed. If the test is to be taken over a period of several days the automatic weighers should be adjusted before the commencement, and, if necessary, during the performance of the test.

(4) The flue dust should be weighed from the precipitator on a carefully adjusted and accurate scale.

From the knowledge given by the weight and ash content of the total fuel fired, the total ash delivered to the furnace can be obtained. Tests on the electrical precipitator at Willesden show that 78 per cent. of the dust passed through a 300 mesh sieve. Similar tests can be applied to other types of dust collection plant.

Typical screen analysis of samples taken from electrical precipitators are as follows :—

Screen mesh.	(1) % passing screen.	(2) % passing screen.	(3) % passing screen.
80	94·5	96·2	95·5
100	92·5	93·1	93·5
150	89·0	89·0	90·0
200	84·5	85·0	86·5
325	74·0	74·5	74·6

These figures illustrate the extreme fineness of the dust delivered to the precipitator and serve to indicate in some measure the nature of the problem of collection.

Regarding the cost of this apparatus the initial capital outlay may be from 2s. to 8s. per k.w. installed. The latter figure is an approximate figure for the electrical precipitator and with greater development and application of this type of apparatus, the price may be expected to fall. It is mainly on account of the high cost of this type of auxiliary apparatus that other types of plant have been preferred.

Sulphur in coals exists in three forms, as pyritic sulphur, as organic sulphur, and as sulphate sulphur. Suitable cleaning or washing processes at the colliery can eliminate much of the pyritic and sulphate sulphurs. The sulphur oxides of the flue gases are thus left to be dealt with at the power station.

From the descriptions of the principal methods of treating flue gases for dust collection it will be seen that the water washing methods lend themselves most readily to the removal of sulphurous matter in the gases. Tests have shown that a considerable amount of sulphur compounds are dissolved or neutralised in the flue gas washing water, especially when alkaline washing waters are used. Tests have been conducted on the solubility of SO_2 in water in order to reduce the amount of water and washing plant required to a minimum. These were conducted in the University of Ilinois and the results have been confirmed by the London Power Co., and the Government Chemist. Various alkaline waters, the use of soda, ash lime, chalk, etc., have been experimented with. The final design of plant for a particular installation takes the form of a two-pass vertical concrete tower with banks of catalytic-iron scrubbers in the first or down pass and wooden scrubbers in the uptake in which the alkaline wash is used. This is followed by a section for the removal of free moisture from the gases. On the experimental plant the operating cost for power and alkali was 3d. per ton of coal burnt.

The Effect of Flue Dust on Electrical Insulators.

Reference to the tables giving the chemical constituents of flue dust and a knowledge of the constituents of flue gases show that these dusts contain matter which is of high electrical conductivity. The deposition of these dusts upon electrical transformer, overhead line, or switchgear insulators increases the risk of their breakdown. The hygroscopic character of pulverised fuel dusts coupled with frequent damping or wetting, and the subsequent drying produce a hard semi-conducting scale upon the insulators. The flash-over voltage is therefore seriously lowered. Outdoor electrical equipments located in the vicinity of pulverised fuel stations require special care and attention to guard against electrical faults. Frequent cleaning of insulators is thus necessitated.

Emissions and the Public.

It has already been indicated that much controversy has arisen of late in connection with the erection of large power stations, especially within the Metropolitan area, and the principal trends of public thought were directed through avenues towards the elimination of possible danger to historic buildings, vegetation and human life.

Evidences of the stir of the public æsthetic and hygienic conscience show that it continues and it seems to increase. There are two possible solutions to meet the new public demand. One is the installation of apparatus to eliminate the evil and the other is to erect electrical generating stations at points remote from the social centres of activity. Both of these alternatives involve additional expense, and the public must be now educated to the fact that in its insistence upon the elimination of these evils it must be prepared to shoulder the financial responsibility involved. Anything which increases the cost of electrical energy is a charge upon the industry, and hence upon the consumer, but it is significant that not all of the public are consumers, and the charge is reflected on to consumers only. It must also be remembered that an extension of the use of electricity results in the reduction of domestic and industrial smokes and the total smoke production from all sources is greatly reduced. The attention of organizers of public opinion is, therefore, directed to these important aspects for operators of electrical undertakings are no more philanthropic than members of other branches of industry, and in this progress towards æsthetic and hygienic satisfaction it is the duty of the public to finance these privileges and comforts of civilisation Sight must not be lost of the fact that there is the prospect of injury to the amenities and products of agricultural areas. Rural and agricultural communities have the right to protest against the possible development. Councils and societies for the preservation of all kinds of amenities of the countryside might also participate in opposition to proposals of possible spoliation. The alternatives are, therefore, to legislate for the benefit of the many or to legislate for the inconvenience of the few. In either case, additional financial burdens may be involved and it is right that the public should view the case in all its aspects and especially in its correct perspective.

Pulverising of Coal at the Colliery.

A movement is on foot in this country to inaugurate the supply of pulverised fuel direct from the collieries to the user. It owes its inception to Germany where this practice has been established for some time and is continuing to gain support and popularity. The advantages and disadvantages of such a scheme as applicable to electricity supply undertakings may be usefully examined.

The utilisation of such fuel would eliminate the necessity of providing capital charges, maintenance and operating charges for local preparation plant. Due to bulk preparation the cost of pulverising would be certainly less than local pulverising. Owing to the use of mass production methods, it could be reasonably expected that a product of greater fineness and uniformity would result. It is reasonable to expect also, that the ash content would be lower; this would follow as a matter of course, as the collieries would find to their cost that suitable coal washing or cleaning treatment is necessary before pulverising. The use of large quantities of electrical energy for power station auxiliaries would be eliminated.

One major result would be the concentration and technique of preparation in the hands of the colliery owner. This is a very proper step as it is reasonable to expect the seller of coal to prepare his commodity for sale in the form demanded by the customer. Electricity authorities are not exempted from this task, whereas the colliery owners have for too long disregarded it.

The disadvantages of the method are rather numerous. Electricity undertakers would be obliged to provide special handling plant for the new fuel, and it might involve dispensing with the old plant and its consequent capital loss. The cost of the new fuel would include the cost of special containers for transport and the cost of handling equipment at both ends of the journey, and hence these items may be quite considerable.

Practical difficulties such as the packing of coal in the bunkers after long periods of storage would render the movement difficult. Moisture accumulation during transport and storage would tend to choke the feeders and hence, special arrangements for drying as at present might be required. The impossibility of keeping reserve stocks of the material on site as is the case with solid coal is a point well worth serious consideration, for not only would normal deliveries have to be punctual but in times of transport dislocation the results of such an absence of reserve stocks would be serious. To meet the cost of the provision of special transport arrangements there would be, no doubt, an increased transport charge.

The design of the boiler feeder arrangements would necessarily be that of the central system but there would be no auxiliary equipment other than the fuel feeders. To deal with moist fuels satisfactorily special drying arrangements would have to be provided and in addition compressors and their associated equipment would be incorporated as part of the fuel reception arrangements.

Viewed from the general aspect there does not seem, at the moment, to be much attraction to the electric power engineer in such proposals. Remembering that the price of the new fuel would be more dependent on other than simple technical or economical considerations, such as the tendency of the colliery owners to increase the price of the commodity after the demand had been developed, it is unsafe to predict that any substantial benefit of such proposals would accrue to electricity undertakers.

Fuel Costs and Operating Costs.

The Author has made excursions into engineering literature in order to obtain precise information on the maintenance and operating costs of powdered fuel and stoker-fired installations. He regrets to state that as far as the latter are concerned, these researches have borne little success. It was felt that in order to be useful in purpose, these costs should be more or less comparative. The costs which were available seemed to indicate an economy by the use of pulverised fuel to an extent of about 5 per cent., but considerations such as station load factor, size of boiler unit and type of firing, system load and operating conditions render individual station costs incomparable and their utility doubtful.

The absence of a uniform method of allocation of station costs, the difference of plant layouts involving several different types of firing added to the difficulty of obtaining reliable figures without mentioning other obstacles which were encountered.

It is certainly most desirable that these figures should be available, and in this connection it is worthy of remark that this state of affairs will not continue indefinitely. It is understood that steps are being taken to ensure that the costs of production of electrical energy at all Selected Stations shall be returned in a standard and comparable form.

Comparison of Sizes of Powdered Fuel and Stoker-Fired Boilers.

A comparison of the relative sizes of pulverised fuel boilers and boilers fired with mechanical stokers is illustrated in Figs. 18 to 21 from which the various pressures and outputs can be obtained. The ratings are the maximum continuous ratings.

In the case of the powdered fuel boilers the ratings are based on burning low grade fuel, but with the use of average quality fuel as generally used in power stations in this country the evaporations could be easily increased to 1,000,000lb. per hour. In the case of the stoker-fired units which are of the same width as the powdered fuel units, the ratings given are those which would be obtainable when burning good average quality coal.

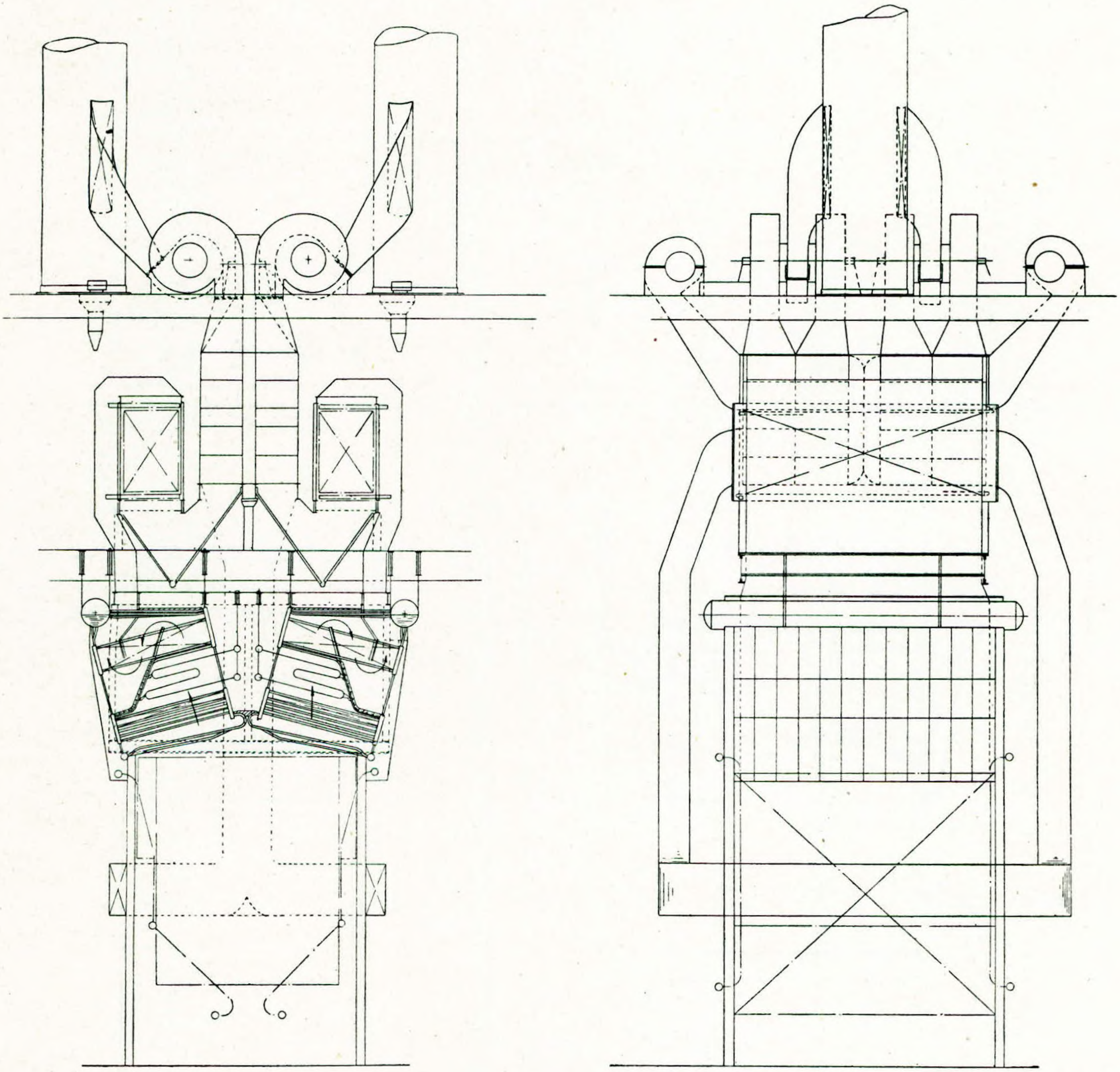


FIG. 18.—Boiler pressure, 34 atmospheres, 483lb. per sq. in. Capacity 880,000lb. per hr. (low grade fuel); 1,000,000lb. per hr. (average fuel).

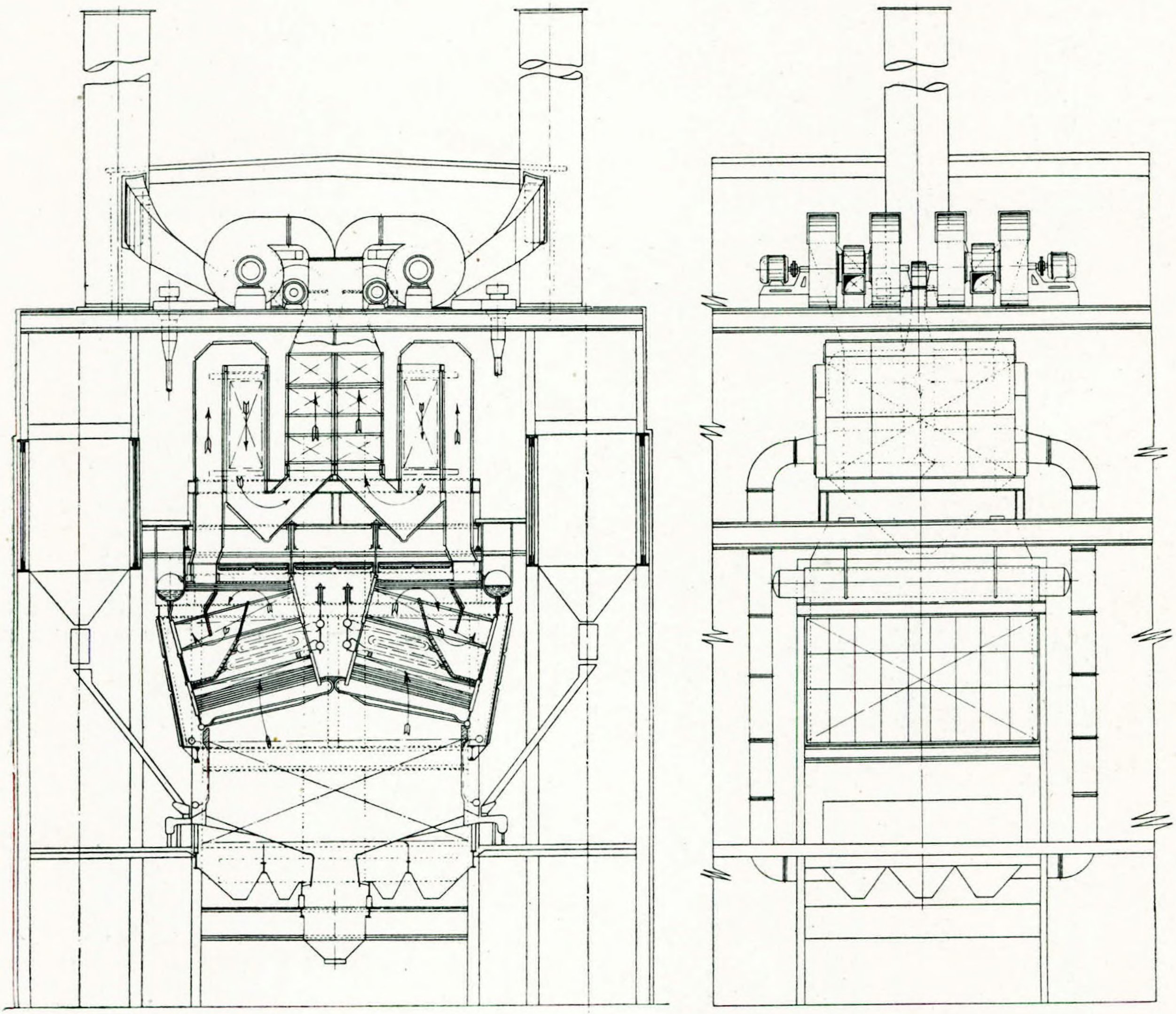


FIG. 19.—Boiler pressure, 34 atmospheres, 483lb. per sq. in. Capacity 800,000lb. per hr (good fuel).

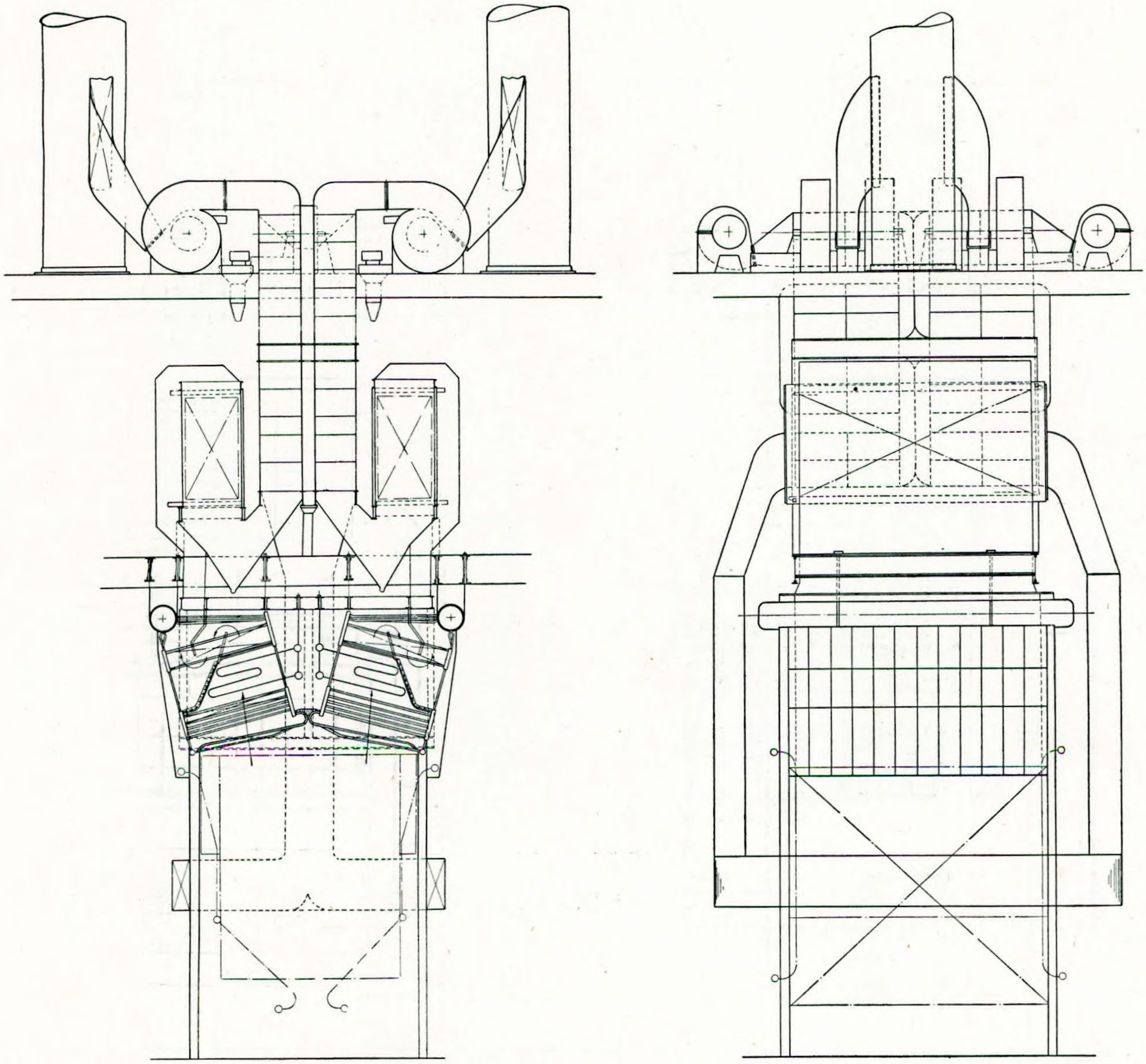


FIG 20.—Boiler pressure, 100 atmospheres, 1,420lb. per sq. in. Capacity, 880,000lb. per hr. (low grade fuel); 1,000,000lb. per hr. (average fuel).

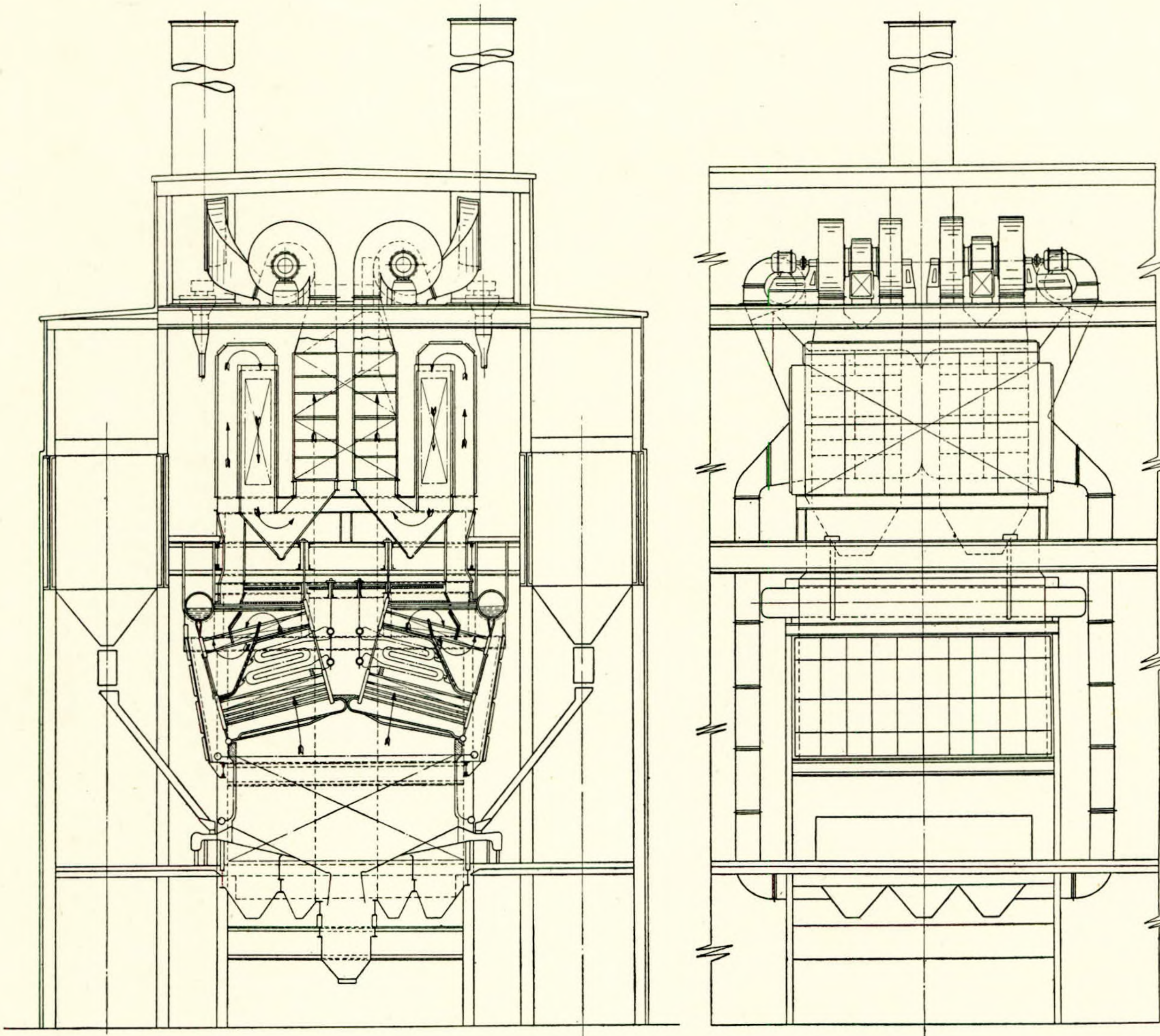


FIG. 21.—Boiler pressure, 100 atmospheres, 1,1420lb. per sq. in. Capacity, 700,000lb. per hr. (good fuel).

Table 8.

Table Showing Relative Progress of Boilers Under Different Types of Firing.

Station and Operating Company.	Type of Firing.	Maximum evaporation lb./hr.	Boiler surface sq. ft.	Water wall sq. ft.	Economiser sq. ft.	Superheater sq. ft.	Air heater sq. ft.	Furnace volume cu. ft.	Lb. per sq. ft on boiler H.S.	Lb. per sq. ft. on boiler and water walls.	Lb. per sq. ft. on boiler, water-walls, and economiser.	Lb. per sq. ft on boiler, waterwalls, economiser, and super-heater.
East River No. 9 Boiler ...	Powdered Fuel	1,250,000	45,340	7,345	15,366	13,900	91,728	41,700	27·60	23·74	18·38	15·26
Hell Gate Station of the United Electric and Power Company	„	1,000,000	52,306	4,590	19,604	12,000	60,500	45,100	19·10	17·60	13·07	11·30
Kips Bay Station of the New York Steam Corporation ...	„	750,000	34,260	8,120	19,656	—	61,440	32,000	21·90	17·70	12·10	—
Vitry Sud Station of the Union d'Electricite	„	300,000	25,300	2,745	13,240	7,260	36,000	16,200	11·86	10·70	7·27	6·18
Ironbridge Station of the West Midlands Joint Electricity Undertaking	„	270,000	21,600	3,900	6,420	7,750	32,000	14,500	12·50	10·58	8·46	6·81
Billingham Station of Imperial Chemical Industries	„	270,000	8,000	2,300	23,030	4,460	9,296	11,020	33·80	26·20	8·10	6·34
Brimsdown Station of the North Metropolitan Electric Power Supplv Co.	„	200,000	19,970	3,539	—	4,900	25,500	10,560	10·02	8·52	—	7·15
Barking Station of the County of London Electric Supply Co.	„	187,000	16,510	1,790	16,000	4,300	19,920	11,450	11·31	10·46	5·50	4·92
Kirkstall Station of the City of Leeds Electricity Dept. ...	„	184,000	16,540	1,490	6,480	4,850	8,270	11,000	11·10	10·20	7·51	6·27
Hudson Avenue Station of the Brooklyn Edison Company ...	Retort-Type Stokers	530,000	24,540	3,750	22,400	5,700	—	15,500	21·60	18·73	10·45	9·40
Battersea Station of the London Power Company	„	330,000	26,580	2,063	17,826	10,120	57,208 Howden 29,000 Rotator	15,910	12·40	11·52	7·10	5·83
Kraftwerk West Station of the B.E.W.A.G.	„	330,000	25,800	805	—	6,450	28,700	16,500	12·80	12·40	—	9·95
Deptford West Station of the London Power Company ...	„	200,000	21,930	1,546	12,870	5,160	32,085	11,340	9·10	8·52	5·50	4·82
Deptford East Station of the London Power Company ...	Travelling Grate Stokers	200,000	15,860	520/767	14,400	3,740	25,668	11,050	12·60	12·20	6·50	5·80

The difference in the evaporative capacity of the pulverised fuel units as compared with the stoker-fired units is accounted for by the maximum combustion rates so far obtained on mechanical stokers. The limiting factor in the mechanical construction in both types at present is the length of drum, but if a demand for greater capacities arises this limitation will be removed.

Comparing the two alternatives it would appear that the use of pulverised fuel offers considerable economy in constructional material even for capacities so close as those under review. Comparing units of say, 1,000,000lb. output, and 250,000lb. output, it is evident that very considerable economy may result in the choice of the former capacity. There are at least two manufacturers in this country ready to undertake the construction of boilers of such outputs.

The Influence of Pulverised Fuel on the Development of Steam Generators.

Satisfactory progress has been made in the past few years in the development of steam generators. Evaporations have increased until a powdered fuel boiler of 1,250,000lb. per hour is now giving satisfactory service; steam pressures have increased and many stations are now operating at pressures between 1,000 and 2,000lb. per sq. in. while steam temperatures have kept abreast until they now range between 800°F.-932°F. Thermal efficiencies of boilers have risen until a boiler efficiency of over 90 per cent. has been claimed, while an overall boiler house efficiency of 86 per cent. has been obtained. Simultaneous with increased operating efficiency, capital investment efficiency has risen due to the capital economy of concentrating outputs into larger and fewer boiler units. Increased evaporations per unit surface area are now possible and the boiler floor space per unit output has been gradually decreased.

To what extent has powdered fuel contributed to this progress? Table 8 may provide the answer, but this answer may not be sufficiently conclusive. It is, therefore, necessary to examine the possible reasons for this progress and at the same time investigate the probable development in the future. Before doing so, it needs no qualification to state that the aggressive advance of powdered fuel, and its influence on boiler design has, perhaps, been the strongest stimulant in the progress of stoker design because in the race for supremacy the stoker manufacturer has had to face similar problems as those found in the use of pulverised fuel, and similar means have been resorted to in overcoming them.

As an example of the efficiency of these large pulverised fuel units, the following extract from the Journal of the American Institute of Electrical Engineers proves that very high efficiency can be achieved.

" Table gives heat balance data of a test recently run on one of these new boilers at an output of 1,000,000lb. steam per hour. This output, which is 25 per cent. greater than the maximum guaranteed capacity of 800,000lb. per hour was maintained continuously for 12 hours with entirely stable furnace and water level conditions and with no signs of distress in any part of the equipment."

TABLE 7.

HEAT BALANCE OF NO. 7 BOILER.
OUTPUT 1,000,000LB. PER HOUR.

	B.T.U.	%
Loss due to moisture in coal ...	11	0·1
Loss due to hydrogen	453	3·0
Dry chimney gases	1,137	7·7
Combustible in refuse	73	0·5
Moisture in air	30	0·2
Radiation and unaccounted for ...	294	2·0
Total losses	1,998	13·5
Efficiency and heat to boiler ...	12,772	86·5
	14,770	100·0

An efficiency of 86·5 per cent. is indicated. For peaks this unit has operated at 1,270,000lb. per hour for 10-15 mins. The efficiency at the normal load of 800,000lb. per hour is 89·6 per cent. Fig. 22 illustrates this boiler.

Drs. Rosin and Marguerre have stated the maximum possible heat liberation for continuous output powdered fuel boilers to be in the region of 680,000 to 780,000 B.T.U's. per cubic foot per hour without the use of preheated air as a theoretical value only. These figures are dependent upon a number of factors which are all well understood. Present practice can affirm normal outputs of 30,000 to 35,000 B.T.U's. per cubic foot per hour, and outputs of 80,000 to 85,000 B.T.U's. per cubic foot per hour as maximum values. The latter figure is claimed to be achieved regularly in the case of a very high evaporation boiler. There is thus, between the lower values and the maximum theoretical value a wide range of possibility of improvement. For chain grate stokers of the largest existing size, and using a moderate air preheat temperature only, maximum outputs correspond to between 45,000 and 50,000 B.T.U's. per cubic foot per hour. For retort type stokers maximum outputs of 75,000 B.T.U's. per cubic foot per hour have been reported, but this figure is based on design data only. Taking the largest contemplated chain grate with an area of 705 sq. ft. approximately (i.e. 32ft. by 22ft.) and assuming the use of a very good class coal the maximum heat liberation would apear to be about 70,000 B.T.U's. per cubic ft. per hour with an air preheat temperature of 350°F. Taking into consideration the difficulty of applying preheated air to either the retort or travelling-grate stoker the ultimate limiting factor to the development of these two would seem to be in the air temperature.

It is an undisputed fact that air preheating possesses considerable economic advantages, for it not only accelerates combustion but it increases the

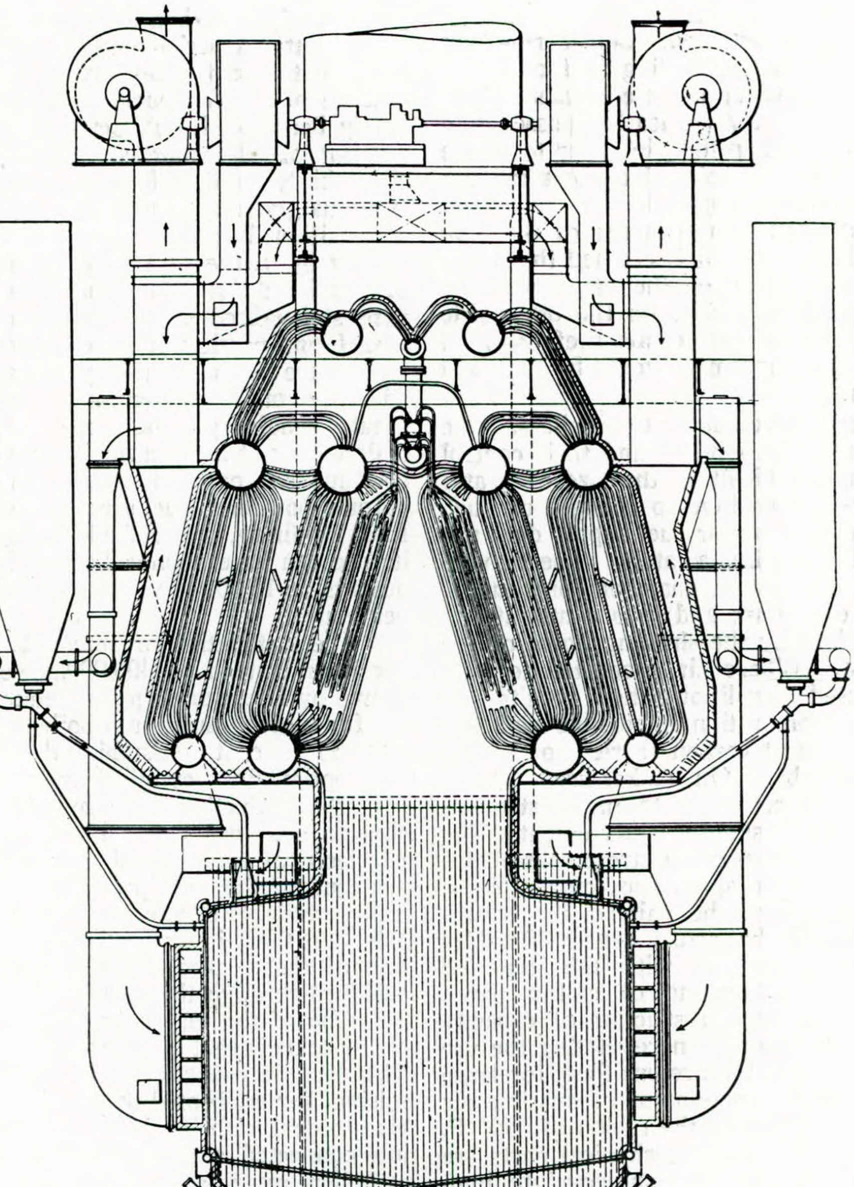


FIG. 22.—*Sectional elevation of one of three 800,000 lb. units to be installed at the East River Station of the New York Edison Company.*

combustion efficiency and improves the overall boiler efficiency. These results are obtained at a capital cost which justifies the equipment of air-heating apparatus. Pulverised fuel plant not only affords a greater heat liberation per unit volume value, but it enables the fullest economic advantage of air preheating to be obtained. Considering that it is cheaper to provide air heating surface in the form of a preheater instead of the equivalent boiler or economiser surface, air preheating possesses a powerful attraction. Therefore, in order to utilize fully these potential economic advantages the use of powdered fuel is pre-supposed.

Opinion is divided on the merits of the bare tube wall. On the one side it is claimed that these walls have a cooling effect on the flame resulting in inefficient combustion, while on the other side large amounts of radiant surface are preferred. It would seem that a compromise would be the most practical solution.

Turning to travelling-grate boilers, the elimination of expansion stresses and their control become increasingly difficult as the size of grates increases. They are sensitive to changes of fuel, and any adjustment of air or fuel supply does not have the desired effect immediately. The moving parts inside the combustion chamber constitute a potential source of failure and thus continuity of supply is jeopardised by the shutting down of the entire boiler unit. Where air preheated to high temperature is used "cauliflowering" results and this renders good combustion impossible and also the quantity of unburnt carbon carried to the ash hopper is considerable. On stoker-fired boilers again temperature effects seem to manifest themselves but perhaps to a slightly lesser extent. The foregoing remarks on expansion stress control, inaccessibility, etc., may be applied to retort-stokers, and if any superiority can be claimed, the advantage seems to be with the retort type. Troubles which have been experienced with this type of firing are burning and breaking of stoker parts, avalanching of fires, and a restriction of capacity due to air-preheating troubles necessitating the use of water sprays. Up to the present time, for large units of 50 tuyeres, the maximum permissible air temperature appears to be in the region of 350° F. In pulverised fuel boilers the mechanical parts are outside the boiler and are not subjected to high temperatures. Reliability is thus associated with accessibility. Plants operating on this system are further enabled to take advantage of high air preheat temperatures and temperatures of 650° F. are now in use. Temperatures beyond this are contemplated.

When these attributes are considered in relation to the higher availability factor as proved by confirmed statistics, powdered-fuel boilers seem to possess those characteristics which are very necessary in modern electric generating stations. Data for 186 boilers in 50 American generating stations using every class of powdered fuel plant indicate that pulverised fuel boilers have an availability or an "in commission factor" of 4 per cent. above that of travelling-grate or stoker plants. Such repairs as may be necessary can be performed quicker on pulverising plant than on stoker plant. In the case of the latter a period must be allowed for cooling down of the parts, and further, these parts are most inaccessible. Tendencies in Germany have recently been to instal stoker-fired equipment on account of the marked increase of flexibility, adaptability and efficiency resulting from the stimulus given by powdered fuel performance and competition, but this new phase has been checked mainly by virtue of the fact that the capital cost of powdered fuel plant compares very favourably with stoker-fired plant. In some instances it has been found possible to effect appreciable reductions and there is a tendency towards considerably wider adoption. Progress is towards units of great reliability, and once future base-load boilers are put into service they will be expected to continue so for many weeks on end. For large outputs powdered-fuel seems to be the pre-destined form of firing, and reliable information suggests its use can be economically justified even down to outputs of 15,000 k.w., corresponding to 150,000lb. per hour.

The installation of boiler plant of 1,000,000lb. per hour instead of 400,000lb. per hour has been shown by Dr. Munzinger to reduce the capital outlay for a given maximum boiler house capacity, by 30 to 35 per cent. Assuming these figures to be unduly optimistic, they still leave a very large margin for the reduction of capital charges. These charges are very heavy in the cost of generation of electrical energy, and may amount to 60 or 70 per cent. of the total production cost. The opportunity available to effect economy is quite considerable, and there is some stimulus towards the adoption of these large units, but this can only be achieved through the agency of pulverised fuel.

One of the major problems in electricity supply systems is that of catering for the "peak load." This load introduces special difficulties in steam raising, for additional boilers must be put into service to deal with it. Where a station is not on an interconnected system the problem is aggravated as boilers must be kept standing by under pressure to meet a sudden demand, or to meet any emergency. Various methods are available for dealing with the system peak, but it is sufficient for this present paper to deal only with special pulverised-fuel boilers for the purpose.

There are two suitable types of boilers being produced, the first of which consists of chain-grate stokers capable of dealing with about 30 per cent. of the total peak load, and having a grate loading of 40 to 60lb. per sq. ft. per hour. Additional steam demand will be supplied by pulverised fuel plant, the capacity of this plant being the remaining 70 per cent. of the total boiler output. It is contended that a reasonably high economy would be secured by the use of these boilers. On peak load highly preheated air would be used for the powdered fuel but cooler air would be used for the stokers, the temperatures corresponding to maximum permissible temperatures for each form of firing. Efficiencies of 78 to 84 per cent. are claimed for this type of boiler between 10 and 60 per cent. full load, and at 70 per cent. to 100 per cent. load 76 to 80 per cent. The Author does not favour the use of these boilers for reasons of the retention of stokers and their disadvantages, the reduction of air temperature which has to be resorted to, and the fact that in summer time the overall efficiency would be lower than that attainable on a straightforward plant. Boilers of this type have been installed in the new Clarence Dock Power Station of the Liverpool Corporation.

The other alternative is the use of specially-designed pulverised fuel boilers. One of these boilers is now in service in the Calumet Station of the Commonwealth Edison Co. The actual steam generating surface is confined to the bank of tubes below the superheater so that the boiler very rapidly responds to variations in the amount of fuel fired into the furnace. When high evaporations are required, a large fuel supply is necessitated, and high exit gas temperature results. The boiler is thus provided with a high-duty steaming economiser, and large water wall heating surface is incorporated. With the application of high temperature pre-heated air maximum combustion efficiency is obtained and on peak load a very high heat transfer velocity results. As air pre-heating may be applied to reduce the stack temperature to a minimum value, high economy is secured.

Comparing the two above alternative methods, it would seem that as pulverised fuel is required for both installations, it would be preferable to utilize the advantage of powdered fuel throughout and to avoid the disadvantages of stokers and at the same time secure the benefits of overall economy.

Fish (U.S.A.), who described the Calumet boiler to the World Power Conference, 1930, emphasizes the fact that " high overload capacity depends on the coal burning means more than any other factor." Accepting this view, what more convenient means could be provided for this purpose than pulverising plant? The separation of this plant from the boiler, the simple method of delivery of the fuel to the furnace and the ability to provide an ample number of burners to meet the required load conditions are attributes which deserve serious consideration. Adequate draught production is an integral part of the coal burning process and the pressure drop across the fuel and stoker bed is objectionable. On chain grate stokers it is necessary to burn a coal containing 5 per cent. ash as a satisfactory minimum, in order to protect the grate, the ash residue forming a protective covering for the links. In retort-type stokers fusing of clinker on the fuel bed occasionally occurs. The increased resistance therefore necessitates increased draught pressure, this feature being absent with the use of pulverised fuel. As the power requirements vary with the cube of the output, this factor may be worthy of consideration.

Several methods have been proposed for the use of high overload capacity turbines for dealing with the system peak load. These will not be discussed, for up to the time of writing no installations have been reported. However, high-overload capacity stations may become established equipments in the future, and associated with the high-overload turbine is the high-overload boiler. It may be that stations of this description may eventually supersede the one-shift and two-shift stations of to-day. The present old stations may be unreliable, they are costly to maintain and to operate, and one alternative to their use is the high-overload peak-load turbo-alternator station. Detailed costs are available on the basis of the chain-grate stoker performance and they show a saving. Further economies might be effected if pulverised fuel firing were chosen.

Regarding the same subject, attention has been drawn by E. Brown to the fact that if stand-by plant were used for peak loads it should be preferably running light ready for any emergency. This operation would entail the use of considerable quantities of steam, and to overcome this forced-circulation hot air has been proposed to keep the turbine warm and ready for service. If it was desired to maintain the turbine temperature to correspond with that of the initial steam temperature of say 700°F. and over, no special preheating arrangements would be necessary in a pulverised fuel station, nor would any practical difficulty arise.

Due to the use of the regenerative cycle on the large turbines of to-day, feed heating temperatures of 300°-350°F. are now usual in all modern stations. There is a strong tendency to increase the number of feed heating stages. It becomes necessary to extract the final heat from the flue gases by means of an air preheater, and the indications are that there may be extended use of powdered fuel boilers in order to obtain the maximum heat extraction from the flue gases.

There is a demand on electricity supply systems for very accurate frequency regulation. Variations of frequency are undesirable for a number of technical reasons, apart from statutory obligations. Automatic control of boilers provides great assistance in the solution of this problem, and to this application pulverised-fuel plants are eminently suited. Much has already been done in this sphere, and the author foresees a considerably increased application in the future.

The principal reasons for the advance of pulverised fuel and its future influence on steam generators may be summarised as follows :—

(1) Highest possible combustion efficiency resulting in high overall efficiency.

(2) Highest possible heat liberation per cubic foot of available combustion space.

(3) The ability to use high temperature preheated air thereby increasing overall efficiency and saving of capital cost.

(4) The elimination of the mechanical disadvantages of grates and stokers when subjected to high temperature.

(5) The greater reliability of powdered fuel boiler units.

(6) The possibility of building the largest boiler units conceived and the attendant economy of capital cost.

(7) The ease of adapting powdered fuel to high overload requirements.

(8) The ease of application of automatic control.

Modern boiler house design is slowly but surely progressing towards the installation of powdered fuel plant. More and more is being pressed into service, and the author ventures to suggest that in the future physical and economical development of large electrical generating stations, pulverised fuel is bound to play a predominant part.

Conclusion.

It is hoped that the treatment of this very difficult and controversial subject has been such that it fairly represents the true position of pulverised fuel firing. The author has not been content to state his own views but he has indicated the general trends in this field of modern generating station boiler house practice from studies of British and foreign literature. To all those sources of information which are too numerous to mention the author offers his grateful thanks, and to avoid invidious distinction it has been decided not to refer to particular sources.

The author trusts that the conclusions which have been reached will meet with approval, and imperfect as this paper may seem, he asks for the generosity of readers' indulgence if reference to any particular phase of this subject has been omitted.

Appendix.

List of Pulverised Fuel Plants in Use in Central Power Stations in Great Britain.

Undertaking.	No. and type of boilers.	Evaporation. Normal. lb./hr.	Evaporation. Overload. lb./hr.	Remarks.
Birmingham Corporation ...	6—Spearing	35,000	42,000	Lopulco
Nechells	4—Simon Carves	150,000	180,000	Simon Carves
Birmingham Corporation, Hams Hall	5—B. & W.	200,000	240,000	Lopulco, Atritor
Brighton Corporation	2—Wood Generators	100,000	120,000	Lopulco
County of London E. S. Co., Barking	10—B. & W.	135,000	187,000	,,
Derby Corporation	3—B. & W.	60,000	80,000	,,
	2—C. S. G.	60,000	80,000	,,
Hammersmith Boro' Council ...	2—Stirling	40,000	40,000	Holbeck
Hayle Station, Cornwall ...	1—B. & W.	20,000	20,000	
Leeds Corporation, Kirkstall ...	3—Stirling	160,000	184,000	Lopulco
Leicester Corporation	3—Lopulco	150,000	180,000	,,
Liverpool Corporation	3—B. & W.	160,000	184,000	Atritor
	3—B. & W.	125,000	156,000	,,
Luton Corporation	2—Woodeson	45,000	45,000	Woodeson
	2—Clarke Chapman	120,000	120,000	Clarke Chapman
Manchester Corporation ...	1—B. & W.	130,000	170,000	Fuller-Lehigh
Metropolitan Rly. Co., Neasden	6—Lopulco	80,000	100,000	Lopulco
North Met. Elec. Power Supply Co., Brimsdown	2—B. & W.	9,600	10,000	,,
	5—B. & W.	100,000	130,000	,,
	4—C. S. G.	175,000	200,000	,,
	1—B. & W.	6,000	9,000	Fuller-Lehigh
North Met. Elec. Power Supply Willesden	1—B. & W. Clayton	80,000	100,000	Lopulco
	2—B. & W.	75,000	90,000	Fuller-Lehigh
Newcastle E. S. Co., Dunston	2—B. & W.	30,000	37,500	,, ,,
	4—B. & W.	125,000	156,000	Clarke Chapman
Peterborough Corporation ...	2—Vickers Spearing	25,000	40,000	Simon Carves
	2—Spearing	80,000	100,000	,, ,,
Poplar Borough Council ...	3—Spearing	50,000	70,000	Lopulco
	3—Spearing	70,000	85,000	,,
Stepney Borough Council ...	3—Spearing	75,000	75,000	Clarke Chapman
St. Pancras Borough Council ...	2—B. & W.	45,000	75,000	Lopulco
	2—Spearing	55,000	75,000	,,
Stretford District Council ...	1—B. & W.	18,000	18,000	Howden-Buell
Trafford Park, Manchester ...	1—B. & W.	20,000	—	,, ,,
Wallasey Corporation	2—Simon Carves	52,500	70,000	Simon Carves
West Bromwich Corporation...	3—B. & W.	30,000	30,000	
West Mid. Joint Elec. Authy. Walsall	3—Thompson	60,000	75,000	Lopulco
West Mid. Joint Elec. Authy. Ironbridge	3—Stirling	225,000	270,000	Fuller-Lehigh
Worcester Corporation ...	1—Stirling	—	90,000	Atritor

DISCUSSION.

The Chairman, on inviting Mr. Twinberrow to open the discussion, pointed out that they had had two or three papers during recent sessions on pulverised fuel and mechanical stokers as applied to marine work, but this was their first paper dealing with land practice.

Mr. Jackson had favoured them with some useful criticisms in the discussions on previous papers. Now they had an opportunity of criticising him and of learning something of the success that had attended the burning of powdered coal in power stations. Incidentally it was hoped that same useful hints would emerge that would prove helpful in marine applications.

Mr. J. O. Twinberrow (Visitor, Messrs. Babcock & Wilcox, Ltd.) said that Mr. Jackson had given an almost heroic paper, not only on account of the work he must have put into it, but for the tremendous field he had covered. Some of the items he had included could easily be expanded into a paper in themselves.

It was very difficult to generalise on the question of stokers versus pulverised fuel, or storage versus the direct fired system. There was good in them all, and each had its own particular application between certain set limits, and it was found that in considering any particular proposal the problem was not nearly so immense as it appeared to be. Taking an extreme case, for example, the burning of slurry automatically confined the problem to the storage system, with probably a separate preparation plant incorporating separate driers.

Looking at the problem from a different angle, as boiler pressures increased so the temperature of the liquid inside the boiler increased, which automatically increased the gas temperature leaving the boiler heating surface. Also the favour shown at the present time towards regenerative feed heating in power stations meant that the temperature of the feed water to the economiser was also very high. These factors meant that the economiser or convection heating surfaces would be comparatively small, and the economiser arranged so that steaming in it could take place. Hence, under these circumstances, in order to reduce the gases to a reasonable temperature, a large air heater must be installed, and at the present time the limiting temperature of the combustion air was much lower with stokers than with pulverised fuel or oil, so that the method of firing was automatically settled.

In connection with the storage system versus the direct fired system there was one point which the author had not mentioned, and that was the question of fire insurance. The following figures, which were three or four years old, it was felt would add to the value of the discussion, in spite of the fact that British insurance companies might not work on the same basis :—

The fire insurance premiums for storage system equipment were in all cases higher than for direct fired equipment. The storage system was generally classified into three divisions, as follows :—

(1) An isolated preparation plant in an entirely separate building placed at a distance from the furnace or boiler building. The rate was 1 cent per $100.00.

(2) A central preparation plant located adjacent to the furnace or boiler room and separated from it by a standard fire wall. The rate was 3½ cents per $100.00.

(3) Where the pulverising equipment was placed directly in the same room or building as the burning equipment. The rate was 10 cents per $100.00.

(4) The rate for a direct fired installation was ½ cent per $100.00.

These were the rates established by the Central Lighting and Traction Bureau, which was an organisation of insurance companies in the United States of America. A large number of representative insurance companies throughout that country were members of this Bureau and their rates were widely used. They had no compulsory power, however, to enforce their rates on insurance companies which were not members. These rates were based on what was called 80 per cent. co-insurance.

He did not altogether agree with the author's statement that bare tube furnaces permitted maximum rates of heat liberation. The author's analysis was perfectly correct in so far as it went, in that a bare tube was approximately a black body and therefore favourable to heat absorption. He thought that probably from lack of space the author had not followed up his analysis, as having got the heat into the wall of the tube it was necessary to get it out and into the water. Furnace tubes were as a rule vertical, and the steam forming on the inside of the tube automatically impeded the heat flow.

In the year 1889 the company with which he was connected made their first installations of bare tube furnaces, and since those early days of bare tube furnaces the company had experimented with and made installations of almost every known type of furnace construction, and it was undoubtedly their experience that maximum heat liberation in the furnace was achieved with covered tube construction of the right type.

The author's classification of the mills was fair so far as it went, but in order to avoid nomenclature of a particular make of mill he preferred a classification somewhat as follows :—

(1) High speed impact type operating over 720 r.p.m.

(2) Medium speed impact type operating between 75 and 720 r.p.m.

(3) Slow speed impact and abrasion type operating below 75 r.p.m.

It would be noted that the Lehigh mill and the Raymond thus fell into Group No. 2, and these mills would probably have to be further classified as to screen or air separation type. The third group would include all types of ball mills, tube mills, etc., and it might be necessary to differentiate between air separation in this type of mill and the type of separation such as was used in cement plants, where the product simply flowed out at the discharge end of the cylinder.

Regarding burners, it was perhaps logical in the early days of pulverised fuel for burner design to follow that of the oil burner, in which atomisation was effected by centrifugal action. It was, however, found that pulverised fuel burners were rather a different proposition, and that if centrifugal action was applied to the primary air and coal, the latter became segregated, resulting in stratification or segregation of the coal, so that all the coarsely ground particles were thrown together at one particular part of the flame, and these were very difficult to ignite. Swirling of the primary air and coal was therefore harmful, swirling of the secondary air, whilst perhaps not harmful, did certainly not do any good. In the design of burners designed by his company no use at all was made of swirling in order to produce turbulence.

He was pleased to see the author advocating the use of coal cleaning. They were not working along the right lines in burning coal in the same state as their grandfathers had done.

He liked to think that there was perhaps an error in the paper where the author referred to periodical boiler tests. Boilers should be run at maximum efficiency, irrespective of load, day in and day out, and if this was done the operation of the plant was one continuous test.

He was unable to see how an alteration of direction of the flame, which the author mentioned, could affect the efficiency of the furnace and boiler, and would be glad if Mr. Jackson would kindly explain this point further.

With regard to tangential firing, he thought the author's remark rather presupposed the admission of secondary air in different parts of the furnace. He liked to look on a furnace and burner as analogous to a cylinder and carburettor of an internal combustion engine. The function of the carburettor was to make an explosive mixture which was put into the cylinder and exploded quickly. The function of the burner should be to make the explosive mixture, which immediately on entering the furnace should be exploded or burnt in as short a time as possible.

Finally, he thought the value of the paper would be improved if a note were given as to the source of information where reference was made in the paper to published tests or reports.

Mr. E. W. Green (Member) said that in the short time at his disposal he had extracted very much pleasure from reading Mr. Jackson's paper. As their Chairman had remarked, however, he was more particularly interested in pulverisation for marine purposes and the technique of the land system was naturally somewhat strange to him.

There were several processes which the author advocated that rather took him by surprise. For example, he suggested drying coal in the pulveriser by exhaust gases as an everyday procedure. In marine practice they did fit a connection to the mill so that in cases of dire emergency, when no dry coal was available, they could use funnel gases for this purpose. But they dealt with a very small combustion chamber, and consequently could not afford to have it filled with gases deficient in oxygen.

The author appeared to favour an arrangement of mill and fan which had never been used in marine installations. If the fan was arranged to blow the air through the pulveriser, the fan was not subject to the erosion of the coal dust, but the mill was under pressure. They always arranged their fan and pulveriser so that the pulveriser was not under pressure. Pulverisers were easier to design if it was not necessary to make them airtight. One could afford a leakage into but not out from the the mill.

He was something of a crusader in the matter of turbulence, which had always been put forward as a great source of economy. He had intended to write a few words against turbulence, but he had found the following passage in the paper which formed an ample basis for the argument he proposed to put forward, viz.:—

> "One more influence remains to be dis-discussed, and this is turbulence. The size of a particle is extremely small, and it possesses very low momentum. The viscosity of the fluid in which it moves increases with temperature, and thus the penetrative power of the particle is decreased. It thus rapidly attains the velocity of the carrying air, in which state it does not acquire the necessary amount of oxygen to complete combustion. . . ."

He asked them to consider this small particle floating in the air. Its condition was unlike that of some firmly supported structure which, when subjected to a storm, would remain stationary while its surrounding atmosphere would be changed. The condition of the particle might be more aptly compared with that of a balloon which, being air-borne, would be carried away with the air and would experience no change of environment.

The chemical potentialities of this glowing particle of carbon were generally overlooked. It was ready to combine instantaneously with any oxygen met with, and the miniature explosion resulting from this combination was sufficient to propel it to the new environment required to maintain combustion.

Mr. Jackson stated that the heat liberation could be increased to 35,000 B.T.U.'s per cub. ft. per hour by the use of "tangential burners which produce greater turbulence." As evidence that this artificial turbulence was not necessary to produce high rates of heat release, the "Hororata," whose burners were certainly not designed to produce turbulence, and so far as he knew did not do so, was maintaining a heat release of 35,000 B.T.U.'s in 20 small combustion chambers.

In conclusion he thanked the author for his extremely interesting paper, from which, as a novice in many of these matters, he hoped to obtain useful information.

COMMANDER H. D. TOLLEMACHE (Visitor) said that he congratulated the author on his extremely interesting paper, which dealt with an enormous field of controversial subjects in a most impartial manner. It was a paper to be kept for future reference.

He desired to continue with the subject of burners and turbulence, as he did not altogether agree with the views of the last two speakers. He thought Mr. Green's contention that a particle would always follow the air current in which it was carried was right only in regard to the minutest particles of coal. It was, however, well known that there was always a grading in size, no matter to what degree of fineness the coal was pulverised, and while it was probably true to say that the surface friction of very small particles, in proportion to their mass, might be sufficient to make them follow an air stream even if it changed direction, the mere fact that impingement and wear was obtained on the pipes and cyclones in pulverised fuel systems, indicated that many particles did not obligingly follow the air stream as suggested by Mr. Green.

If one analysed the requirements of a burner it was, he thought, possible to introduce two further lines of thought to those suggested in the paper. Firstly, it was now becoming realised that an efficient burner should be capable of controlling the course of the particles in relation to their size. With the ordinary rotary burner, for instance, when the coal dust left the burner orifice, the larger particles which required the longest time to burn were thrown out and away from the flame zone, whereas the finer particles requiring the least time for combustion were retained in the middle. The tendency of modern burner design was now following the exact converse of this principle and so distributing the particles of coal in the combustion chamber that the larger were concentrated in the centre of the flame zone, where they were surrounded, and assisted in their combustion, by an envelope of easily ignitible fines.

Secondly, it was now being realised, as Mr. Jackson pointed out on page 115, that the rate of flame propagation of a powdered fuel cloud definitely governed the speed at which the fuel could be injected into the combustion chamber of the boiler. For many reasons it was desirable to keep the entrance velocity of the fuel into the boiler as low as possible, as it reduced the tendency to impingement and bird-nesting, and also gave the requisite time element to facilitate combustion. Obviously, however, the speed of entrance should not be reduced below the rate of flame propagation of the fuel stream, or there would be a danger of firing back into the system.

Modern burner design now appeared to be following the lines of reducing the permissible speed of entrance of the fuel cloud by separating the mixture into two streams of different densities, one on each side of the curve on page 115. For instance, the curve of 30 per cent. volatile and 15 per cent. ash in the fuel showed the maximum rate of flame propagation to be about 36ft. per second. If that fuel mixture were separated by the burner into two streams, having densities of 2lb. and 7lb. of air per lb. of coal each, a flame propagation rate of 20ft. per second would be obtained, which would consequently enable the powdered fuel to be blown into the combustion chamber at a much lower velocity in the two streams than if the mixture was retained in one stream.

Another item of great interest, which the author referred to on page 136, was the question of the preparation of pulverised coal at the colliery. This was already being carried out extensively in America and Germany, and although Mr. Jackson appeared to think that this procedure was rather too far ahead for consideration at present in this conservative country, it seemed obviously right, in principle, that the coal producers should be responsible for preparing their fuel in the way consumers required it. If it was possible to get the energetic co-operation of our coal owners in the production of powdered fuel at their mines, an important step would have been taken in combating the competition they were suffering from oil.

In the case of the big power stations the maintenance and operating cost of all the pulverising machinery was a large item, and a power station, like other business concerns, was out to sell its commodity and not to use it. If a considerable quantity of the electricity produced was used for local power station requirements, then the output available for sale was correspondingly reduced.

He believed that if the colliery owners would have the enterprise to lay down pulverising plant, and to supply clean powdered coal so that when a consumer received a wagon of fuel he knew he was receiving a good wagon—full of heat units, they would be taking a practical step in supplying the needs of the modern method of burning coal.

Mr. John Reid (Visitor) said that he proposed to follow the lead given by the Chairman, and discuss the paper only with reference to its interest for them as marine engineers.

Some progress had undoubtedly been made in applying pulverised coal to marine boilers (Scotch and water-tube types), but there were two obstacles in the way of its more general adoption. One was a high first cost which could not be justified unless associated with positive maximum furnace and boiler efficiency and fuel economy, and the other some doubt as to reliability, especially with certain qualities of coal which might have to be bunkered at foreign ports.

It must never be overlooked that an owner's idea of boiler efficiency and economy was not taken from thermal data, but from bunker checks and daily consumptions, and in comparing anticipated fuel results for pulverised coal with the actual results from the bunker figures, a mysterious discrepancy was always found. This should be attibuted to the loss of valuable fuel dust and unburnt carbon to the funnel, and so overboard. The underlying cause for this heavy loss of fuel was the mania for carrying a hurricane forced draught effect at the furnace, precluding early ignition and introducing an element of time lag in the combustion process fatal to furnace and boiler efficiency in Scotch boilers.

In the splendid land plants which Mr. Jackson had described and illustrated, great attention had evidently been paid to building up under the boiler proper a most effective type of furnace, the principal characteristic of which was a tubular water wall. Marine engineers were a modest race of men, but they might take credit for the fact that half a century ago the designers and constructors of Scotch boilers had fully developed a water-walled furnace, perhaps the most efficient and economical conceivable. Unfortunately the most had not yet been made of its possibilities with any form of combustion, either with coal or oil fuel, but signs were not wanting that a better policy lay ahead in this respect, and the introduction of pulverised coal was one of the reasons for that.

Everyone agreed that a most important consideration in connection with furnace efficiency with pulverised coal was the extreme fineness in grinding required at the mill. Unfortunately this desideratum called for an expenditure of power which could not be lost sight of when the heat account was made up, since it might involve 4 to 5 per cent. of the total steam raised in the boiler, and even higher percentages when a steam engine was used to drive the pulveriser. This placed the advocate of pulverised coal for marine boilers on the horns of a dilemma, as it was necessary either to keep on grinding until an ideal fineness was reached at a high expenditure of power or to stop grinding earlier and lose overboard a high percentage of large dust particles which could not be completely burned in the furnace. The total heat loss for grinding and carbon loss to funnel in average cargo boat Scotch boiler work, even with good bunker coal (bituminous quality), had averaged in his experience nearly 10 per cent. of the total fuel fed to the furnaces, and these were the problems which remained to be dealt with to ensure success with pulverised coal in marine work.

In a Scotch boiler burning pulverised coal there were three furnace characteristics of major importance for efficiency; these were frequently referred to as the three "T's", viz., time, temperature and turbulence, and the greatest of these was *time*. Several speakers, however, had referred to turbulence, which was also very important, and more effective in a Scotch boiler furnace than in any other. Turbulence as applied to combustion processes was never a confused milling about of the dust particles with the air molecules regardless of relative quantities, velocities and temperatures, but, on the contrary, must be a deliberate attempt in the mouth of each furnace to so deliver and control the fuel and air supplied that an effective mixing, early ignition, and quickest heat release might be brought about in the first half of each furnace barrel.

This was where time, or rather timing of the combustion relative to correct flame development and propagation came into play and the greatest enemy of success in this all-important consideration was a hurricane delivery of the fuel or the air supply or both into the furnace beyond the burner. If it was remembered that a furnace suited to pulverised coal burning was invariably under a distinct vacuum effect produced by the funnel draught or pull, and that the burner contributed an injector effect to the secondary air supply surrounding it, the absurdity of adding a high static pressure to the fan air became at once apparent. Any fan air speed over 30ft. a second was clearly inadmissible beyond the burner, but sixty to a hundred feet a second for this velocity was frequently attempted, and was inevitably associated with uncertainties caused by the air volumes delivered being extremely prejudicial to furnace efficiency.

It was well known to many of the members that there had been a revolution in this matter of air pressure in the past few years. He had himself been brought up on the theory that it was necessary for coal burning to put 3in. w.g. on the fan and 1in. w.g. on the ash pits in hand-fired practice. Now they were down to something like $\frac{3}{4}$in. at the fan and no air pressure in the ashpits. No matter how the pulveriser dust entry was slowed up it was going to pull the secondary air in behind it, and fan pressure was, consequently, not necessary for the secondary air. He might say that although this might appear to be only an expression of opinion, he had already conducted numerous tests on Scotch boilers on board ship on this basis.

When they were testing burning arrangements on a Scotch boiler with one or two furnaces he recommended that they should always aim to convert what they got into an equivalent to be obtained on board a ship. He always tried to keep the fan pressure down to ¾in. w.g. and to regulate the secondary air supply to the work that was being done by the burner, which was beneficial to the secondary air delivery.

Referring again to turbulence, it was necessary to relate turbulence to the type of boiler that was being worked. It should be remembered that a Scotch boiler furnace was a large draught tube, and while the axis was horizontal, if the fuel was properly projected into the furnace with secondary air around it, combustion would take place close up to the burner nozzle and close up to the furnace walls.

It was impossible to get a Scotch boiler furnace into good working condition if the heat absorbing surface was choked with a lot of brick. This had been done in the early days even with oil fuel. Ensure combustion as early as possible, and they would get the heat through the water walls as effectively as possible!

On the trials of three or four successful pulverised fuel burning Scotch boilers which he had attended temperatures were taken by pyrometers and thermo-couples. Temperatures of 2,600 to 2,700 degrees were shown. The object of pulverised fuel was not to get such a high temperature, which simply proved that the heat developed was not getting through to the water. He had therefore asked that temperatures should be taken at the smokeboxes, and he had not been surprised to find that these ran to 800 deg. F. and over.

In conclusion he said that a great deal of their furnace troubles could be attributed to this hurricane forced draught effect, which was never necessary, and which was always prejudicial to effective combustion. Had this been recognised earlier, progress with pulverised coal burning would have been much further advanced, and many apparent failures could have been easily converted into successes.

Mr. E. K. Regan (Visitor, Messrs. Powell Duffryn Steam Coal Co., Ltd.) said that he assumed the author's references to flame length and output of furnace referred to fishtail burners and high volatile coal, as he found that with lower volatile coals (which were not generally regarded as suitable for pulverised fuel work) flame lengths of less than 20ft. could be obtained, particularly with dispersive type burners.

Referring to the question of unit drying, i.e., drying the coal in the pulveriser, it had to be kept in mind that whilst the moisture was driven from the coal it still remained in the circuit and its projection into the furnace with the fuel feed appeared to chill the flame.

The coals mentioned in the author's paper appeared to be all of one class, i.e., with reference to their volatile content. He had had considerable experience with pulverised fuel and proposed to give some abbreviated data of the performance of a colliery plant which was burning coal of 11½ per cent. volatile content with an average ash content of about 16 per cent. This particular plant was quite a small unit of about 30,000lb. per hour evaporative rate, the mill being of the impact type. This had been in service since 1927 and the following was an extract from the plant records.

The continuity of service, which was an important factor in any boiler plant, was found to be 81 per cent. of the available time; this included voluntary and involuntary shut downs and the annual survey of the boiler. The efficiency on the lower value of the coal over a period of 5,260 hours was 85.1 per cent., including the economiser. Cost of renewals to the mill (not including labour) was 2d. per ton, which, in view of the ash content of the coal, could be considered a good performance. The life of the mill parts subjected to wear was 2,468 hours before complete renewal was necessary. It was found that there was very little drop in efficiency when operating down to 50 per cent. rating, whilst it was possible to operate flame to 25 per cent. rating. Furnace brickwork renewal charges had been so low as to be almost negligible. Excess air had been limited to 38 per cent. It was later found that increasing the tube exposure over the furnace, together with the inclusion of tube sweepers in the scheme practically eliminated bird-nesting on the tubes, this also being assisted by the high fusion point of the ash. He thought that his figures might be of interest in view of the fact that this class of coal was not usually supposed to be suitable for pulverised fuel firing. The experience with this particular plant, however, had been so gratifying that further larger units were being laid down.

He thought that the author had been rather unfortunate in his experience with British coal, as he had stated that it varied considerably in quality, ash content, etc. He (the speaker) would like to refute that, as coal could be and was supplied to-day as uniform in quality as most commodities. Mr. Brownlie had commented on the fact that 10 per cent. of the whole output of the coal of this country in the form of ash (amounting to thousands of tons per annum) was being moved about the country by colliery and railway people. He would like to point out that perfectly ash free coal would be very undesirable from the users' point of view, although it would be rather a good thing for makers of firebars, stoker links, etc., due to the rapid deterioration of grate surfaces which would result from the use of an ash free coal. It was found that a 5 per cent. ash content coal was almost necessary, excepting for pulverised fuel, in order to prevent damage to grate surfaces. Coal as a commodity was not peculiar in that one purchased something with it that one did not want. For instance, cigarettes were accompanied by sundry wrappings and a carton, and he invited them to consider the quantity of water travelling about the country in the form of, say, jam or soap.

After reading the author's notes regarding coal he had looked up particulars relating to a contract for the supply of 2,000 tons per week to a large power station, and on the receiver's own analysis the variation in calorific value over six months' period was only 2 per cent. either side of the guaranteed figure. It might be mentioned that nowadays many coal contracts included a penalty clause to cover any deterioration in the calorific value of the coal delivered, but although it was frequently found that deliveries were above the stated figure, it was a difficult matter to get a bonus clause incorporated in a contract.

Mr. P. C. Pope (Secretary, Institute of Fuel) said that Mr. Regan had referred to coal containing 11½ per cent. volatile content as having been successfully dealt with in a powdered fuel installation, and mentioned it as somewhat unusual. He had seen a plant in operation at the Lincoln Hospital, New York, where they were trying quite successfully to burn a coal with 6½ per cent. volatile content. They had used this very low volatile fuel to a much greater extent than we had, and more successfully. That was on a Babcock and Wilcox boiler.

A reference was made by Mr. Jackson to a slide illustrating the Barking Power Station and the small amount of smoke from the chimneys. He had seen the plant in operation and found that it was not smoke at all, but ash. It looked like smoke, and it was just as thick.

The question of drying by flue gases had been discussed. There were a good many troubles in flue gas drying, one being that it did not eliminate the moisture but carried it into the furnace in another form. If it were dried before being fed to the mill, that moisture would be saved from going into the furnace.

Another point was that if one used too high a temperature in drying the coal—the bituminous coals particularly—one was apt to soften the coal and make it very sticky, thereby causing cauliflowering. In one case when a non-coking coal had been substituted, the cauliflowering ceased.

The author stated that in the central system "condensation should be guarded against by suitably insulating the bunker and by circulation of warm air or warm flue gas and air through the bunker." To circulate warm air through the powdered fuel bunker was highly dangerous, as it simply asked for spontaneous ignition due to oxidation of the coal, particularly with certain classes.

Mr. Twinberrow produced a very nice analogy, namely, that of the carburettor and cylinder of the motor-car engine, and said that the fuel should be prepared before it was put into the combustion chamber. There would be a great improvement in many, particularly the Scotch, boilers, if a little more attention were given to the very ingenious burner designed by the Fuel Research Board, the "Vortex" burner. The Board had done their duty in producing this burner, and it should be the work of other people to make use of it.

With the "Vortex" burner in operation the larger particles remained for a longer period in the combustion chamber than the smaller particles, giving greater time for the combustion of the former. It was not really a burner, but a gas producer. The actual heat released in the combustion chamber had been got up to as much as 500,000 B.T.U.'s per cubic foot per hour. Practically a gas producing effect was obtained, and gas was turned out into the combustion chamber of the boiler, mixed with the secondary air and caused combustion, thereby preventing particles leaving the burner and going into the combustion chamber of the boiler.

The Fuel Research Station would be very glad to give assistance to any manufacturer willing to go into the matter. It appeared to be the ideal burner for Scotch boilers, as it gave the conditions of combustion, without the hurricane, as desired by Mr. Reid.

Mr. R. H. Gummer (Visitor), Messrs. International Combustion, Ltd.) said that he desired to congratulate the author on his noteworthy paper, which was the dividing line between the past and present. It was a new vintage. The early vintages were very sour; the new vintages, which Mr. Jackson had presented in his paper, were much sweeter. Many years experience had now been obtained in this country, and this paper enabled them to see more clearly into British operating practice.

He would like to remove an impression which might have been created by the remarks of the gentleman who opened the discussion on the relative cost of insurance for direct and central-fired plants, by quoting the excellent experience that had been secured in this country in favour of central-fired plants based on their operations on a very large scale. The advantages were greater reliability, low first cost and operatinig costs, and the lower costs of maintenance. For these reasons the insurance companies favoured the central system as compared with the direct system.

Then, again, the central system ensured better continuity of the degree of fineness with which efficiency was definitely associated in pulverised fuel installations, whether land or marine.

If there was one criticism that he had to offer it was that the author had neglected to refer to reliability. He had had the privilege of being with a number of engineers in Germany and had seen a pulverised fuel boiler of 300,000lb. per hour capacity which had been in continuous operation for 8 months. This was a degree of reliability which, he thought, had not been previously equalled.

In conclusion he would like to ask the author the following questions :—

(1) What in Mr. Jackson's opinion was the influence of grinding on the final efficiency of the boiler plant?

(2) What views had Mr. Jackson on the increased cost of grinding or pulverising at a high degree of fineness, as the higher degrees of efficiency were usually associated with the finest particle obtainable?

(3) Could Mr. Jackson give his opinion as to the effect of increased turbulence and more intimate mixing, and its relation to the degree of grinding which should be established?

(4) As coal characteristics varied so considerably, what was the influence of a low CO^2 content on the efficiency with a very friable coal and a definitely low ash fusing temperature?

(5) Could Mr. Jackson give any information as to the effect of the widespread use of pulverised fuel systems both in England and the Continent on the British coal industry?

(6) What was the largest pulverisied fuel installation in this country and could he give particulars of units?

(7) Could Mr. Jackson give any reasons for or against its more rapid adoption in marine vessels?

(8) How much increased efficiency would he expect to obtain on a well-managed marine installation?

(9) How much more reliable were the modern pulverised fuel plants as compared with those installed, say, five years ago?

(10) How did present-day capital costs compare with an equal size of stoker-fired plants?

One speaker referred to the slow progress made in marine circles compared with the many wonderful land installations. He would say to this gentleman that the progress of land installations was largely due to the fact that the electrical industry of this country had fortunately escaped the effects of the world-wide depression and had been steadily expanding. As many of those associated with these splendid pulverised fuel installations had had the benefit of a marine engineering training, they would be very ready to co-operate with present-day marine engineers in developing marine installations still further immediately the long-desired improvement in trade conditions permitted shipowners to expand their activities once more.

Mr. W. Hamilton Martin (Member) said that the author, under the heading of "Dust and Sulphur Emissions" on page 134 of his paper, referred to some comparative tests carried out on corrosion and erosion of materials exposed to the action of sulphurous gases, in which the relative rates of corrosion (or erosion) were determined. The best result was shown by a sample of a 24 per cent. chromium, 12 per cent. nickel alloy, which lost only 0.3 grammes per square foot per day. The comparatively high percentage of chromium and nickel would not be conducive to low cost of such an alloy. These tests, it was presumed, were carried out a good while ago. It had lately been found that in all cases where gases of high sulphur content had to be withstood, the complete absence of nickel in any material exposed to such action became highly desirable.

He had occasion to give particulars of some new lowly alloyed heat resisting steels before this Institute when discussing Mr. McNeil's paper on "Nickel and Nickel Alloys in Marine Engineering" on 8th December last, materials which he had pointed out were specially resistant to high sulphur containing gases as they did not contain any nickel, which element was known to be so very sensitive to sulphur absorption.

Although the materials quoted were primarily evolved as heat resisting steels, and were non-scaling, and had proved excellent for highly rated superheater tubing, etc., the fact that they showed special resistance to such active gases as—

> air and strong dioxide containing gases, strong carbon containing gases, compressed hydrogen at elevated temperatures, and strong sulphurous containing gases,

would seem to point out that they would probably compare very favourably with the 24 per cent. chromium and 12 per cent. nickel alloy the author mentioned as the best one to resist sulphurous gases.

He would recall here that Mr. Laslett, discussing Mr. McNeil's paper, pointed out that "nickel had proved itself somewhat unsatisfactory in alloy steel, and had had to call in the assistance of chromium, even then the results, so far, had not been all that could be desired." Mr. Laslett mentioned this, no doubt, in relation to nickel alloy superheater tubing which was exposed to high pressure and temperature, as well as furnace gas action; sulphurous fumes might become specially active in such cases.

Immunity from the effects of temperature in burners, furnaces, etc., arresting corrosion in parts exposed to active gases, such as draught fittings, air heaters and ash handling parts, would all seem to be cases where materials containing nickel were not desirable, because of the presence of sulphurous and other deleterious gases.

The availability of suitable lowly-allowed, and consequently reasonably-priced, materials, should largely contribute in the near future towards the securing of service reliability and economy of operation of power stations, as described by the author, whose experience of the behaviour of nickel alloys exposed to active gases and to high temperatures would be appreciated.

He fully agreed with the remarks made in connection with the elimination of vibration in mills and machinery.

Their compliments were due to the author for his comprehensive and informative paper.

MR. A. G. BUGDEN (Member) said that Mr. Gummer had mentioned that a number of marine engineers, of which he (the present speaker) was one, took the question of pulverised fuel in hand in its early stages. They had certainly had a lot of American knowledge to go upon seven years ago, and they had since turned that knowledge into wisdom.

Some of the author's assertions rather provoked controversy in view of the fact that two of the large power stations at Barking and the Synthetic Ammonia Company's Works had reverted to stoker firing.

He was afaid that the designs given in the paper were, to the marine engineer, rather complicated, as large central station plants were illustrated, due to the fact that most of the large companies favoured the central system. Very much simpler plans could be and had been designed.

It was to be regretted that the illustrations, with one exception, indicated only one type of boiler, and that a type which he understood was least suited to pulverised fuel firing.

These new methods of combustion required new heat absorption units, and he thought, to complete the illustrations, all the latest designs might be incorporated.

He had been very interested to hear the remarks of Mr. Green, Commander Tollemache and Mr. Reid on turbulence. In relation to this question he would like to recount that two years ago two manufacturers came to him to sell burners. One required twice the air pressure of the other, and the efficiencies guaranteed were the same. Incidentally he had been connected with two systems, each having the two types of burner, and the carbon loss was about the same in each. He agreed with Mr. Green that this turbulence idea was rather a fad and that it appeared a waste of power to design burners with such a high degree of turbulence.

He thought that it was also to be regretted that the mills of only one manufacturer had been illustrated, although they had in one illustration a small view of a Fuller-Bonnot mill.

He would like to ask Mr. Jackson if the figures given on page 119 referred to peak loads, and whether the increase in absorption to 35,000 B.T.U.'s per cubic foot per hour referred to an actual test?

He gathered from the paper that the author suggested that coal drying by gases was most favoured, and he would be glad to have the author's further remarks on this point.

It would also be interesting if Mr. Jackson would give some figures for the maintenance costs of the plants with which he had been directly associated.

He would also like to know whether it was advisable to furnish oil fuel burners for lighting up pulverised fuel burners?

Might he ask whether the Synthetic Ammonia Co.'s mills were not the Raymond but the Hardinge type?

In conclusion he thanked the author for a really excellent paper, his only criticism of which was in regard to the illustrations.

THE CHAIRMAN remarked that he had listened to the paper and the resulting discussion with great pleasure and, he hoped, profit.

It was evident to him that the disposal of ash and the emission of dust from chimneys were giving power station authorities much concern; the same problems worried engineers afloat, though perhaps not quite in the same way.

The operation of boilers with a view to minimising these nuisances was a matter of experience and skill, but a good deal could be done by the provision of suitable apparatus or in the original design. For instance, the accumulation of fine ash in the back ends of Scotch boilers had always been a bug-bear to the pioneers of pulverised fuel, but he noticed the other day that in a Calais dredger, having two Scotch boilers burning powdered coal very satisfactorily, openings were provided in the back ends to free these spaces of any such accumulations of ash, instead of attempting to draw the stuff out through the ashpit (which should be reserved for the withdrawal of slag), or trying to blow it up through the tubes into the smoke boxes and out of the funnel.

He believed he was right in saying that most, if not all, marine engineers who had studied the subject felt instinctively that the use of pulverised coal was bound to come in due time, just as oil fuel did years ago; but it would only come after a long and arduous period of trial and error—as in the case of oil fuel.

A paper and discussion such as they had heard that evening was a valuable contribution towards that desirable end, and they were much indebted to Mr. Jackson for what had rightly been described as an heroic effort.

In conclusion he proposed a vote of thanks to the author, and this was warmly and unanimously accorded by the members present.

By Correspondence.

Mr. G. J. Wells (Vice-President) said that the only fault one could find with this paper was its volume, and the consequent difficulty entailed in discussing it adequately. One feature stood out pre-eminently and placed this paper in the front rank, i.e., it was absolutely free from commercial suggestions and dealt exclusively with the technicalities of the powdered fuel problem.

During the presentation of the paper one's thoughts went back to fundamentals, as the aim of most engineers concerned with power stations was, of course, to reduce the inevitable losses incurred by the transformation of the heat energy supplied into the mechanical or electrical energy delivered.

Internal combustion engineers removed nearly all the plant between the fuel and the engine, and thereby gained simplicity and directness which eliminated labour, capital costs and plant depreciation. Dr. Diesel set out to produce an engine which would achieve this when the fuel was powdered coal, but found the difficulties too great and substituted crude oil. In doing so he undoubtedly advanced the efficiency of transformation. At the moment it would seem that the Diesel type was preferable to coal dust for marine purposes, although this position might be modified in the future. Was it impossible, however, to substitute for the complicated nest of mills, huge furnaces, etc., shown in the author's figures, some form of gas producer using small coal, not necessarily ground so uniformly fine as appeared to be desirable in pulverised fuel plants? A type of producer such as Mr. Wollaston, of Manchester, had designed would appear to be a possible line for development for marine purposes.

On page 125 the author stated that "it is easy to arrange for the sampling of fuel. . . ." This did not agree with the experience of large coal consumers. The taking of samples so that the results obtained were a fair average of the whole bulk delivered was actually very difficult in practice where coal was delivered in large quantities in the usual way, and one would like to know why it became so easy when it was powdered. The suggestion that coal should be bought on a "calorific value basis" was a sound one, if it could be realised. It appeared to be like buying gas on its calorific value, but the therms have to be counted by a gas meter. Incidentally, a therm was a unit of heat; the dimensions of a unit of heat were therefore $(\text{length})^3$!

Another curious point of similarity with a gas or oil engine emerged when the author stated that in one of the illustrations shown the hot products of combustion were utilised for drying purposes, and so got carried back into the furnace. In the early days of the gas engine a certain school of engineers taught that some of the products of combustion *should be left* in the cylinder to dilute the incoming charge of gas and air, and that in so doing efficiency was increased, but to-day scavenging arrangements were employed.

He observed that a thermal efficiency of 89 per cent. was claimed on page 129 for a prominent power station supplying electric energy at sixpence per unit. This brought to mind an incident concerning fish. A deputation of fishermen waited upon a railway manager in order to get a reduction in the rate for the carriage of the fish. When the manager said, "What is the value of the fish?", the reply was "About a penny each!" The manager then said that "The carriage was a very small fraction of a penny, whilst his fishmonger charged him *sixpence* each." The engineer appeared to be like the railway company, for whilst he was engaged in reducing charges down to vanishing point, the salesman was getting all.

Mr. J. R. Douglas (Member of Council), in a written contribution, said that he had found the perusal of Mr. Jackson's paper very interesting, and that he greatly regretted that he had not been able to be present to hear the discussion on this—from a national point of view—most important subject.

He had had some practical experience of the use of pulverised fuel in one of the first marine installations, and he thought that they on the marine side would have to agree that if they wanted to succeed and obtain economical working of a coal job at sea they should give water-tube boilers a trial. While he agreed they could get fair results with single-ended Scotch boilers which had been specially designed, having extra large furnaces and combustion chambers, there was, to his mind, no doubt of obtaining much better results with specially-designed water-tube boilers, preferably direct-fired.

He was afraid, however, that if the small percentage of saving given was the best that could be guaranteed, there was little likelihood of much development in this direction, for so far few had had the courage to state what the cost of conversions had amounted to.

Combustion was, as the author stated, a very complicated process, and more so in a 3ft. 6in. or 4ft. furnace than in a water-tube combustion chamber where more space was available. He would like to add that when combustion as nearly perfect as was humanly possible (as shown by means of all known tests and the use of numerous special instruments) had been obtained, it was found that the result was very little better than when using hand firing, simply because some unknown factor had stepped in and upset the balance; when this had been rectified, another cropped up, and so on.

One of the essentials for good burning was that the coal particles should be very small and be intimately mixed with highly preheated air just before entering the furnace. He was afraid this was where so many jobs had failed. The fuel must complete its combustion before it came into contact with any cold surface, otherwise it was damped out and became a source of loss.

From their own observations the quality of coal was most important and the less ash percentage the better. Unfortunately, however, the market price for a good class of small coal was the same price as for large and, due to this short-sighted policy, the mine-owners had retarded progress.

Then in marine jobs the question of the disposal of ash always arose, and where people said they had no trouble in this direction he would expect to find no economy over hand-firing, as the velocity of gases in that case must be too high to allow sufficient time for the fuel to burn. His continental friends who had experimented with pulverised fuel confirmed his own experience regarding this.

However, time and experience would no doubt solve this question, but he felt they must design special boilers to suit pulverised fuel if they were going to obtain a commercial return for the expenditure. Conversions were, to a great extent, a waste of money. No one would consider converting a steam engine into an internal combustion engine, or vice versa. Let them get down to common sense and build something suitable for use with pulverised fuel and then they would have results.

Mr. John H. Anderson (Member) said he was sure they were all indebted to Mr. Jackson for his paper on pulverised fuel firing with special reference to power station practice.

He regretted very much that the author had not gone more into its application for marine practice, because anything that would tend towards the continued use of solid fuel and the prevention of competition by liquid fuel, so that they could continue using a natural product of this country and thereby create employment, would be a benefit deserving of much appreciation to-day. Apart from the national financial position, the more coal produced with the same overhead charges the cheaper would be the cost. This in turn would assist them to restart their steel manufacturing and exportation of coal, with a consequent reduction in the amount to be found to maintain the balance of exports over imports.

There were two paragraphs in the paper he did not like. These were :—

(1) On page 110 the author said, "It is not the object to apply either heat or fuel of any description to this controversy."

(2) On page 127 he said, "It is not until recent years that much interest was taken in coal technique. The use of pulverised fuel has contributed in no small measure to this progress.

Regarding the first, as the paper bristled with heat and fuel suggestions, surely they might be forgiven if they agreed or disagreed with some of the suggestions.

As regards the second point, he hardly thought marine engineers could be accused of lack of interest in fuel consumption. He wondered if the author could credit, say C. W. Williams, of about 1840, and, later, D. Kinnear Clark and many others, with this lack of interest, and further, if he could suggest anything about fuel that was not known in Williams' time, many years before the idea of an electricity generating station had been germinated.

Of course the writer was not referring to the more efficient machinery, better refractories, automatic controls and registers, etc., but to the knowledge possessed by their grandfathers that all fuels possessed a calorific value depending on the percentage of their various elements, each of which gave a fixed heat value per lb., and that the combination of these, together with sufficient oxygen and a favourable temperature, would give perfect combustion; they could do no more to-day. He suggested that not one iota of improvement in this knowledge could be added. They could, however, and were making steady progress in collecting a few of the heat units that hitherto had been wasted. In this respect he agreed that at a certain cost pulverised fuel was a step in that direction.

Apart from calorific value, there was a deal more in coal than that which the author made use of, and when it was possible to have the combination of electricity generation with gas and by-products production they would get nearer the ideal.

Referring to page 107 of the paper, it would be interesting to know what the author meant to do with the large quantities of low-grade high-ash high-moisture high-sulphur fuels that gave excellent results in other forms of stokers when he said that "high calorific low ash coals of uniform grading provide the most suitable conditions for ensuring efficient combustion and that rival systems of firing may be eventually displaced," particularly as he also said that public attention might have a far-reaching influence on the location of generating stations? He (the writer) expected the meaning of this was that if high ash and sulphurous fuels had to be burnt, owing to the dust and smell, the generating station would need to be erected miles away from the populace.

Taking into consideration that generating costs were a small item compared with transmission costs, and that transport of fuel would call for additional capital and working costs, this meant that they either must tolerate an inconvenience or pay more to have it removed. The latter alternative had the further disadvantage of providing an excuse for some more of those hideous overhead cable supports, etc., which spoilt the beauties of the countryside.

Referring to page 110, would the author say which of the two systems he would install in a ship? For land work the author preferred the central system. Would he put this aboard ship and what space would he allocate for the storage, taking into consideration the seriousness of spontaneous ignition and the danger of explosion and the valuable cargo space and charges involved?

Regarding the combustion of pulverised fuel referred to on page 111, the author said this was an extremely intricate and complex process. Would he tell them why, providing the necessary fuel, oxygen and temperature were supplied, there could be any more intricacies than in the proper consumption of fuel of any kind?

So far as turbulence was concerned, would it not be more to the point if the author took into consideration that there were two distant combustions to take place, the second of which could not start until the first was done? Even the burning of a candle possessed the same properties, and one could obtain a good practical lesson from such an insignificant thing as its combustion, which like all fires followed a natural law and would not burn properly in adverse conditions.

Then, again, on page 113, the author rather suggested that the design of combustion chambers should consist entirely of heat transfer surfaces, as the bare tube wall permitted the greatest radiation on account of being a black surface. Unless one had an extraordinarily large combustion chamber this went against practice, because if there was a surface which gave quick cooling it must to some extent prevent perfect combustion; in fact one of their principal difficulties in marine practice was the large area of cooling surface compared with the size of the combustion chamber.

Regarding preheated air, there surely could not be a claim for this as a novelty. They had been using this for many years now; in fact many years ago it was suggested that a combination of chemical processes might extract the nitrogen from the air and give a higher percentage of oxygen in the remainder, this smaller volume to be heated, thereby putting the same waste calories into a smaller volume and preventing such a large volume of inert gases going into the furnace.

On page 116 the author said it might be inadvisable to employ delivery temperatures of 180-190 deg. Fahr. on account of storage temperatures. Would he not be more candid and state definitely that it was certainly dangerous to do this, and was so even at the limit given of 110 deg. to 120 deg. Fahr.?

He could not quite understand what the author meant by risk of combustion. Was this not a misnomer? Was it not a fact that coal at *all* temperatures was always in a state of combustion, and that it was its rate of combustion that was altered by increase of temperature, this of course being primarily due to its oxidation? He (the writer) suggested that the term used by the author should be " spontaneous ignition," which was the effect of a natural law of accelerated combustion.

Taking into consideration that coal in the ordinary course of mine production would lose approximately its own volume of methane in a few days at atmospheric temperatures, he would like the author to say whether in his opinion the heating, grinding and storage of ground fuel as used in the central system did or did not affect its heat value? Further, so far as the grinding of the fuel at the mine and the time taken until the ground fuel was used, it should be remembered that all the hydroscopic moisture was driven off at the heating and grinding and that this fuel on re-cooling would again absorb exactly its original percentage of moisture from the atmosphere. Would the author be prepared to suggest that this fuel should be transported in hermetically sealed receptacles to prevent this loss, or would he suggest trying to transport it in their existing wagons? The former would be rather an expensive system both in capital and maintenance costs, apart from the carrying to and fro of the idle weight of the receptacle, and as for the latter, the writer was afraid that his experience taught him that there would be very little fuel left in the wagon if the transportation of dry coal dust of 200 mesh size was attempted in an ordinary coal wagon.

It rather looked as if the author desired to be rid of the grinding problem. They were willing to wash the coal, crush and grind it, and transport it at a cost. Was it not rather a confession on the part of the author that he did not want the grinding? He wanted the coal made free of ash and of high volatile content. This was just the coal that, from a national point of view, should not be used in furnaces. Why not use gas and be finished with the troubles?

Interesting figures of 5 to 30 per cent. were given by the author for the ash content of fuel. Some of the power stations mentioned used many thousands of tons of coal in the course of a year. The writer wondered if the author could show them that there was no room for complaint from the nearby population by telling them how much of this 5 to 30 per cent. of ash was actually recovered? The remainder presumably went to atmosphere. Would the author also give the cost of ash recovery by the various methods used, particularly that of the electric system?

The writer suggested that the method of sampling fuel was very crude indeed. It might do for testing the size of dust, but would it be fair to compare fuel heated up rapidly, both by artificial heat and friction, with that taken over by, say, a shipment of 3 or 4,000 tons and where crushing and drying was done by a fixed standard? The writer agreed that the analysis of the samples taken by the author's method would do for a rough comparison taken at the same place, but certainly not for comparison of other methods of sampling and analysis. He was afraid that with such a heating taking place, much of the volatile content was driven off. Did the author get any material of a tarry nature in his pipes or grinders, and with the pressure in these machines would it not be better to have a partial vacuum and prevent any leakage of material or forcing of the dust into places not desired?

The author again referred to using a chosen coal, preferring a clean coal of low ash content. This was all very well, but the writer thought a little experience of marine work showed that one had to be thankful if at some foreign ports something that could be encouraged to burn was obtained. For this there could be no standardisation, and the best had to be made of it.

He quite agreed with the author regarding the flexibility of pulverised fuel firing, but there were at least two points the author had not mentioned which the writer had noticed at sea. He had recently had experience of a very novel type indeed. The ship had half of its boilers working with pulverised fuel and the other half hand firing. The difference in the two stokeholds was extraordinary; hand-fired boilers were indeed heavy toil both in firing and cleaning fires; more or less all the time some of the furnaces were open, allowing cold air to impinge on the heated surfaces which, apart from the heat losses, must continuously keep the furnace flue racking due to expansion and contraction caused by the sudden change of temperature in these tubes. In the other stokehold men, comparatively clean, were quite comfortably paying attention to their duties, and there was certainly a consistent, even temperature in the flues all the time, which no doubt added to the life of the boiler.

Regarding the life of grinders, the author gave them a time for this, but what he omitted was the cost of repairs to those grinders. He suggested in connection with grinders that they should be constructed to give out no noise. This might not be a serious matter in land work, but for marine work it certainly prevented the utilisation of certain instruments used on deck.

Lastly, would the author say what savings, if any, there would be, taking capital cost into consideration, of changing a plant over from, say, chain grate stoker to pulverised fuel stoking? Would he also give similar information for the change to Scotch boilers aboard a ship?

THE AUTHOR'S REPLY TO THE DISCUSSION.

The author, in reply, said that the discussion not only had proved the existence of continued interest in powdered fuel firing problems, but, judging by the absence of serious criticism of the paper, gave an indication of more general support of this method of firing than it had obtained in the past few years. He was happy to be the recipient of such generous approval of his work.

He had given in the paper a general review of boiler house practice as he saw it, and from his own experience of several forms of firing he did not feel disposed to favour any firm if it seemed to be unjustified.

To Mr. Twinberrow he was indebted for his remarks on the insurance rates of direct-fired boilers, and the information he had provided was a valuable contribution to the subject under discussion. Regarding his remarks on the analysis of the combustion process he had supplemented the author's comments with some useful information. On the question of completely covered tube construction the author felt that this should not be so, as he was of the opinion that suitable proportions of radiant refractory surface and bare tube surface represented the best solution. On page 141 the author had stated that "the best solution would be by a compromise between the use of bare walls and refractories."

Referring to the limited classification of mills, he would state that the classifications given were general only and he had not sufficient space to permit wider classification.

Mr. Twinberrow also advocated continuous boiler operation at the maximum efficiency. The author suggested that one did not know whether the boiler was operating at its maximum efficiency until it had been tested and he had indicated that tests were necessary in order to determine any falling-off in efficiency. He agreed that it was necessary to operate boilers at the maximum efficiency rating, but this could only be determined after having been previously tested out.

As regards references, space difficulties partly explained the omission, but it would have been invidious to single out for special comment any particular source, especially when due acknowledgment had already been made.

Mr. Green's remarks were very useful and interesting, but the author could assure him the flue-gas drying was quite standard practice in new installations, and on older installations a great number of conversions had been effected.

Regarding turbulence, the author would like to ask what other method could be employed to secure association of air and carbon? It was not strictly true that the particle was air-borne. In regard to his analogy of the balloon, the author could draw one equally as good to support his case.

A particle possessed considerable momentum due to the fact that it was injected into the furnace at speeds of 140 to 180 feet per second and it did not lose its penetrative power or momentum immediately, despite the high viscosity of the gases. The disintegration of the particle mentioned by Mr. Green actually occurred after the initial heating and drying stage, but during this period it was necessary to maintain the turbulence by mechanical means, and thus it was not true to say that the combination of carbon with oxygen was instantaneous and did not require any assistance. It occupied a very definite period, which varied from about 0·05 seconds to 3·0 seconds, and it was dependent upon the multifarious factors, some of which were mentioned in the paper and which could be greatly enlarged upon. Even after the disintregation of the particle it was necessary to ensure a sufficiency of oxygen in order to complete combustion and it was thus essential to maintain turbulence. The evidence obtained from a number of eminent authorities, including Rosin himself, emphasized the necessity o turbulence, as did practical experience.

On the question of the heat liberation values given on page 119, these were given in order to indicate in a general manner the progress with different types of wall and the effect of the tangential system of firing. They were average values only, but peak liberations over, say, hourly periods might be considerably greater. Heat liberations of over 85,000 B.T.U.'s per cubic ft. per hour were mentioned in the paper, but these had been exceeded and reached 100,000 B.T.U.'s per cubic ft. per hour on short periods only.

He thanked Commander Tollemache for his remarks, and he agreed with him that it was essential to accurately classify the fuel particles, and he welcomed his support on the question of the air-borne particle. With regard to the former, Commander Tollemache had introduced a line of thought which deserved serious consideration and which might lead to greater knowledge on the subject. Whether the burner was the proper point at which to make classification was yet to be determined. It seemed to him that complete classification should be made at the mill exit and the actual distribution at the burners; in other words the reduction and classification process should be completed at one point and the distribution and injection at another.

He had given his support to the pulverising of coal at the colliery in a well-reasoned case, but the author would reply that as a method it was ideal, but the practical issues defined in the paper were those which would govern the decision of the electric power engineer. Were the necessary co-operation forthcoming, the method would be very suitable, but even co-operation was insufficient, for undertakers required reserve stocks on site, absolutely punctual deliveries and the feeling of security from th effects of industrial disputes, because the disadvantages mentioned in the paper rendered storage very difficult.

Mr. Reid spoke of Scotch boilers, but the author had had no experience of this type of boiler, nor had he any marine experience of pulverised fuel firing. It was very gratifying to be supported once more on the issue of turbulence, and the author thanked him for his remarks and illustrations on the difference between draught and turbulence. It was important that marine engineers should recognise this difference and Mr. Reid had the thanks of the author for pointing it out.

Referring to the remarks of Mr. Regan on drying, it was not the case that the moisture chilled the flame any more than firing undried and moist coal into the furnace. The temperature of the coal at the burner might be 180 deg. F., and this acted similarly to the effect of preheated air. In any case, it would be a difficult problem to eliminate the moisture from the drying air, and it appeared to the author that what was really necessary was to remove the moisture from the coal in order to render it workable.

As regards the coals mentioned, they were certainly not all one class as far as the place of mining was concerned. Perhaps Mr. Regan and the author would be in agreement if they had an agreed definition of "class," as Mr. Regan would be aware of the many different methods of classifying coal. In regard to the volatile matter, it was desirable to use coals of high volatile content, as coals of this description produced accelerated combustion. The results which Mr. Regan described were certainly very creditable and were bound to be a source of satisfaction not only to the user, but the manufacturers.

As regards his comments on the inconsistency of fuel supplies the author had yet to be convinced that this was not the case. He thought it was a general experience of all undertakings that coal varied in quality, and the author knew of two stations in London where the deliveries varied in calorific value by much more than the 2 per cent. mentioned, and this referred to a consumption of between 200,000 and 300,000 tons a year. In regard to the cost of 2d. per ton milled on page 123, this should read 3d., and it included maintenance, labour, electrical power and certain miscellaneous costs, but no capital costs. The author had mentioned in the paper that one of the disadvantages of other forms of firing was that the fuel must contain a certain proportion of ash in order to eliminate grate deterioration, and the author thanked Mr. Regan for his confirmatory remarks.

Replying to Mr. Pope the author was glad to learn of the successful consumption of the low-grade coal he had mentioned. On the question of flue-gas drying, external heaters or dryers had been found definitely unsatisfactory, and the general experience in America, as well as that of the North

Metropolitan Company, indicated the necessity of dispensing with them. On the subject of the circulation of warm air or flue gas through the bunkers the author considered that low temperatures of say 110 deg.—120 deg. F. were not dangerous. Thermostatic damper control could be used to ensure this. Mention was made in the paper of the use of CO_2 extinguishers.

He was well aware of the existence of the "Vortex" burner, but owing to the fact that it was at present in the experimental stage it was not included. He joined issue with Mr. Pope in paying tribute to the staff of the Fuel Research Station at Greenwich, as they had undertaken very useful work.

In answer to the helpful contribution of Mr. Gummer, the author would prefer to reply to his formidable questions separately, as follows :—

(1) The author's opinion was that fineness of pulverisation was greatly contributory to higher boiler efficiency. Coarse grinding led to a higher percentage of carbon in the ash, and it was necessary to maintain the fineness of the mill product with strict regularity in order to maintain the maximum degree of efficiency. Central systems in general maintained a greater degree of pulverisation as compared with direct-fired systems operated on certain types of mill, but there was no reason why fineness should not be maintained on direct-fired systems.

(2) The costs of pulverising depended upon two main factors :—

(a) The type of machine selected.

(b) The class of coal to be pulverised.

Progress in the past few years had been such that a very wide choice of machine selection was now available. Low power and maintenance costs were first essentials, and it was worthy of note that on a large plant in the North of England the plant had not been opened for repair despite a throughput of 80,000 tons and the power consumption was 9 kw/hr. per ton. Some manufacturers had test houses in which different types of plant might be tested out and they were in a position to recommend the best type of plant to install for given conditions on the basis of actual test results. With certain classes of coal it was difficult to obtain good average efficiencies at very low operating costs. In these cases it might be advantageous to sacrifice boiler efficiency by using a coarser product with lower power consumption.

(3) As explained in previous answers the author was of the opinion that fineness of pulverisation and the highest degree of turbulence were essential characteristics in the successful operation of pulverised fuel installations. Referring to the tangential system figure in the paper it would be seen that owing to the great intimacy between air and coal the exposure of a completely water-cooled furnace to a very intensive flame could be permitted without any irregularity of the flame. However, the author would incline to the view that although this could be done a small amount of refractory surface could be usefully employed.

(4) Where coals of low-fusing temperatures were used they were invariably very friable and capable of being ground to extreme fineness. If the furnace was run at a high temperature heavy slagging would occur. Providing a reasonable CO_2 content was maintained, high efficiencies could be obtained with such coals owing to the extremely low carbon content in the ash and the low power consumption. The expense of slag removal might, however, be increased.

(5) Although the author had defined in the paper the best classes of coal to be used, the use of pulverised fuel had enabled European fuel users to make greater use of low grade fuels than previously. These fuels were formerly incapable of being burnt on other firing equipments. The use of these fuels had been of great benefit to the coal industry in this and other countries.

(6) The largest pulverised fuel units in Great Britain were at the Imperial Chemical Industries Works, Billingham. There were eight 260,000/295,000 lb. per hour units working at 800 lb. per sq. in., 800 deg. F., and they were of the "Lopulco" type. This plant was capable of generating well over 2,000,000 lb. steam per hour.

(9) and (10) These two questions could be answered together. The author had given his own views in the section dealing with the influence of pulverised fuel on steam generation. He would quote an authority—Mr. John Bruce—who had stated :—

"Assuming correct design and application, pulverised fuel equipment gives to the boiler plant a greater degree of reliability than does stoker plant. The adoption of pulverised fuel plant made possible the installation of these larger boiler units, and he suggested that for the modern generating station of around 300,000 k.w. capacity an economic case could be made for the adoption of pulverised fuel units having individual capacities of 500,000lb. per hour. This size and type of plant offered advantages in reduced capital cost on plant and buildings, simplicity in layout and operation and —not the least important—a very considerable saving in operation labour".

Mr. Hamilton Martin had referred to the comparative tests on the various alloys, and the author would assure him that these tests were quite recent. The tests had been undertaken at the express request of a leading electricity utility company in America, and the conclusions reached had been stated in the paper. Admittedly, the proper material had yet to be found, and it seemed that no sooner had the metallurgist found the appropriate material for one set of conditions than he was confronted with new problems. The whole course of engineering progress had been and would continue to be dependent upon the correct choice and availability of suitable materials.

Referring to Mr. Bugden's remarks, the author said that he could not speak for those authorities who had reverted to other forms of firing but he could only add that he considered their decision had been based on the question of dust emissions more than on the question of capital cost, operating efficiency or reliability.

On the subject of illustrations, the "proof of the pudding was in the eating", as the efficiency figure quoted on page 129 referred to the type of boiler illustrated in Fig. 2. As this figure of 88·8 per cent. was an average figure it would appear that considerably higher efficiencies must have been obtained. It was therefore difficult to appreciate upon what grounds this type was considered unsuitable.

As far as the necessity of new heat absorption units was concerned, the author contended that the type illustrated had been found definitely suitable in practice. Modifications were, however, found to be necessary, but these were quite insignificant as the boilers illustrated on pages 109 and 132 were now operating very satisfactorily and reliably. Mechnical details which had been found unsatisfactory had now been modified, but there would appear to be no necessity for the re-designing of the whole unit. The form of firing employed had, in the opinion of the author, less influence on boiler design than the steam pressure and temperature conditions. The design of the heat absorption unit illustrated was fundamentally sound and as an indication of this it had achieved almost universal popularity whenever steam was being generated under any method of firing. It might, however, be useful to state that any need for special units had been met, and these units had already been referred to in the Transactions of 1931, pp. 364-370.

On the subject of lighting-up boilers by means of an oil fuel burner, this was certainly good practice. Paraffin burners were equally suitable. The question really lay in the willingness of the user to provide the additional auxiliary equipment.

Replying to the question of the type of mills at Billingham, they were of the Hardinge type and they had given reliable and economical service.

Turning to the Chairman the author said he felt honoured to have had him occupying the chair on this occasion. He thanked him for his complimentary remarks, and said it was very encouraging to know that Mr. Gibson's authoritative views on marine firing suggested that the standard practice for power stations might eventually be powdered fuel firing.

Mr. Wells stated that sampling was very difficult, and with this view the author did not quite agree. If samples were taken from six or eight places from each truck and also on suitable points after leaving the bunker in the pulverising circuit, reasonable accuracy could be expected. Supposing a station used 120,000 tons per annum, then the number of individual samples obtained would be about 75,000 from the wagons alone. If hourly samples were taken on each mill (as would be the case in an efficient station) the number obtained might be in the neighbourhood of 60,000 to 70,000 per annum. An accurate average value could, therefore, be obtained which assisted any checking which might be necessary. In addition, the coal as delivered from the wagons could be compared with the coal as delivered to the burners. The difference between the two might be less than 10 B.T.U.'s in 12,500 B.T.U.'s if a good system had been adopted.

The author was appreciative of the remarks of Mr. Douglas, especially in regard to the sale of coal. He thought that the time had arrived when coal factors had to consider the requirements of coal buyers. The absence of co-operation was evident and he felt that it would be to the interests of producers and users if an attempt were made to convert chaos into organisation and efficiency. Producer, transporter, and user were inter-dependent upon each other and only co-operation of activities could bring about the desired result.

The author would like to assure Mr. Douglas that he could not understand how he came to the conclusion that pulverised fuel firing efficiencies were only at the level of those of hand firing. In the cases of the large plants dealt with in the paper the boilers could not conceivably be hand fed, and, even if they were, the efficiency would be greatly inferior to that of mechanical stoking.

The author would inform Mr. Anderson that he could only confine himself to his subject, because, as he had mentioned in the introduction of the paper, he had no direct marine experience of pulverised fuel. As regards the two paragraphs that Mr. Anderson did not like, the author certainly forgave him for any divergence in their views; in fact, discussions had for their object the ventilation of them. As regards the first disagreement the author still felt he had dealt with his subject impartially as the words were intended to imply and he had fulfilled his object of avoiding acrimonious controversy as the discussion in the Institute had proved. The observation that he hardly thought marine engineers could be accused of lack of interest in fuel consumption was irrelevant, because the author did not deal with marine-engineering problems, as the title of the paper obviously indicated. The suggestion of Mr. Anderson that not one iota of improvement in fuel knowledge could be added to that of our grandfathers was regrettable. Surely that statement was too sweeping and it certainly did not do justice to, and precluded the recognition of the valuable work of humble and eminent investigators the world over.

On his remarks on electricity generated from gas and by-products, the author had had direct personal experience of the largest electricity system in this country where this was done and he was in agreement with the proposal, although the paper did not deal specifically with that aspect of generation of electrical energy. Incidentally, under the Electricity (Supply) Act, 1926, the authority created under it might avail itself of the use of waste-heat resources if it was considered advisable to do so.

As regards his remarks on the use of low grade fuels, the location of generating stations and the transmission towers, the considerations affecting these were fully explained in the paper, and the author would state that anything which increased the cost of electrical energy of public supply authorities only encouraged the installation of private plants which were not only less efficient, but were not subject to rigorous and stringent public control.

Mr. Anderson had referred to the design of combustion chambers and the necessity of providing heat reserve and the ensuring of a high furnace temperature. The remarks on page 113 gave the theoretical considerations, but it was the opinion of the author that it was necessary to employ a proportion of refractory radiant surfaces.

Turning to the utilisation of delivery temperatures of 180° - 190° F., the author did not intend to avoid the issue and he was perfectly candid when he stated that it was not definitely dangerous to do so. It must be remembered that the pulverised fuel did not remain in the bunker for very long periods. In support of his assertions, there were many instances where this was a regular practice.

The question relating to the cost of repairs to grinders could not be easily answered, because it depended upon a variety of circumstances such as the class of mill used and the class of coal chosen. As mentioned in the paper the overall cost might be expected to fall to 3d. per ton, a figure which included all charges excepting capital and depreciation charges and the proper proportion of administrative expenses. A reasonable figure for repairs would be from 1·10d. to 2·0d. per ton milled for the Hardinge type of mill, where these figures included labour, etc.

Finally, he stated that he had set out to show that powdered fuel plant produced a higher boiler efficiency than any other form of firing, that high capital charges might be reduced by the adoption of larger pulverised fuel units, and that there might be a reasonable reduction in maintenance costs. He did not know whether he had succeeded but there was at that meeting some indication of support and approval, as these contentions had not been challenged.

He thanked all those who had contributed to the discussion, as their remarks gave some support and encouragement to those interested in pulverised fuel firing.

CORRESPONDENCE.

A New Theory of Screw Propeller Action.

3, Central Buildings,
Westminster,
S.W.1.
March 30th, 1932.

To the Editor of The Transactions.

Sir,—Referring to page 76 of the March Transactions I note that Mr. Kari has assumed that my remarks were based on two-bladed propellers, whereas the print I produced at the meeting showed the usual three-bladed propeller as fitted in all high-powered destroyers.

It will be clear by reference to Figs. 1 and 2 on page 72 that only *one* blade is being discussed. It is shown in full lines *descending*, and in dotted lines *ascending*, with a view to illustrating the change in virtual pitch (Fig. 2) in half a revolution, and the consequent severe changes in stress resulting in heavy vibration at the stern. At first sight the diagrams look like a two-bladed propeller, but the above explanation will remove all doubt.

Yours faithfully,
J. Hamilton Gibson.

Milburn House,
Newcastle-on-Tyne.
April 11th, 1932.

To the Editor of The Transactions.

Sir,—Referring to Mr. J. Hamilton Gibson's letter of the 30th ult., I very much regret the misunderstanding as regards the number of blades, but my attitude towards Mr. Gibson's method of treatment remains unaltered as the number of blades would not affect the validity of his reasoning.

Yours faithfully,
Alexander Kari.

INSTITUTE NOTES.

ELECTION OF MEMBERS.

List of those elected at Council Meeting held on Monday, April 4th, 1932.

Members.

John Edward Francis Burn, 51, Pavilion Road, Worthing, Sussex.

Gilbert McKinnon Clark, 47, Waverley Gardens, Crossmyloof, Glasgow.

John Cox Daniel, 11, Eliot Street, Bootle, Liverpool.

William Dick, 90, Wanstead Park Avenue, E.12.

George Frederick German, 3610, Durocher Street, Apt. 6, Montreal, P.Q., Canada.

Donald Stewart Kennedy, Halidon, Bridge of Weir, Renfrewshire.

Frederick George Roynon Piddington, 146, Lee Street, Hull, Yorks.

Sydney Davison Scorer, 9a, Esplanade, Greenock, Scotland.

Ralph Seymour-Shave, Machinery Engineer, Mokameh Ghat, Bengal and North Western Railway.

Frederick Eugene Verano, 29, City Mill Lane, Gibraltar.

William Bernard Whitty, 31, Tasburgh Street, Grimsby.

Edward Chrystie Younge, 9, Newborough Avenue, Sefton Park, Liverpool.

Associate Members.

Savell Hicks, Glen Druid, Shankill, Co. Dublin.

Thomas Hopes, B.I. Engineers' Club, Box 296, Calcutta.

Wilfred McDonald, 12, Campbell Terrace, Fulwell, Sunderland.

Francis Jolly Smurthwaite, 67, Wolseley Road, Byker, Newcastle-on-Tyne.

Emmanuel B. Zacharis, 78, Bab El Akhdar Street, P.O. Box 11, Minet El Bassal, Alexandria, Egypt.

Transferred from Associate Member to Member.

Charles Ritchie, 3, Dee Village Road, Aberdeen.

Transferred from Graduate to Member.

William Joseph Wilson, Lyndhurst, Ravenscourt Grove, Hornchurch, Essex.

Transferred from Graduate to Associate Member.

Edward Richard Hall, B.Sc., 734, Barking Road, Upton Park, E.13.

BOARD OF TRADE EXAMINATIONS.

List of Candidates who are reported as having passed examinations for certificates of competency as Sea-Going Engineers under the provisions of the Merchant Shipping Acts.

For week ended March 10th, 1932:—

Name	Grade	Port of Examination
Elfert, William E.	1.C.	Newcastle
Beadle, Jack	2.C.	Newcastle
Hall, Robert	2.C.	"
Young, William E.	2.C.	"
Virtue, Frederick G. ...	2.C.	"
Allcock, Samuel A. ...	2.C.	Liverpool
Hebden, Alfred J.	2.C.	"
Biggam, John	1.C.	Glasgow
McKendrick, James W. ...	1.C.	"
Potter, David	1.C.	"
Adamson, Samuel S. ...	2.C.	"
Livingstone, Robert L. ...	2.C.	"
McLennan, Duncan ...	2.C.	"
Shirra, James W. M. ...	1.C.M.	"
Ryan, William L.	1.C.	London
Heyward, Sydney A. J. ...	2.C.	"
Everett, Bernard S. ...	2.C.M.	"
Copland, Thomas C. ...	Ex.1.C.	Liverpool
Smith, Gilbert T.	Ex.1.C.	"
Wood, John S.	Ex.1.C.	"
Liddell, Thomas W. ...	Ex.1.C.	London
Pemberton, Arthur G. ...	Ex.1.C.	"
Wilson, Arthur H. ...	Ex.1.C.	"
Parkin, Fred	2.C.M.E.	Newcastle
For week ended March 17th, 1932:—		
Findlater, John B.	1.C.	Glasgow
Sclater, James B.	1.C.	"
Mackenzie, Thomas ...	2.C.	"
Watson, David C.	2.C.	"
Jones, John O.	1.C.	Hull
Hodgkinson, Cecil F. ...	2.C.	"
Shores, Wilfred	2.C.M.	"
Ashley, Walter C. C. ...	1.C.	Liverpool
Inglis, John C.	1.C.	"
Johnson, Thomas	1.C.	"
Lucas, Charles A.	2.C.	"
Stockham, Stanley E. ...	2.C.	"
Williams, Henry A. ...	1.C.	London
Parker, Harold A. ...	2.C.	"
Thomas, Joseph	2.C.	"
Coulson, Robert	1.C.	Newcastle
Groves, Ronald G.	2.C.	Sunderland
Talbott, Harold M. ...	2.C.	"
Stockdale, William K. ...	1.C.	"
Robinson, Cyrus W. ...	1.C.	"
Brown, Donald E.	1.C.M.	"
Bingham, William G. ...	1.C.M.E.	London
Fortune, Frederick W. ...	1.C.M.E.	Sunderland
Sneddon, Arthur R. ...	1.C.M.E.	London
For week ended March 23rd, 1932:—		
McNeish, James M. ...	1.C.M.	Liverpool
Pawson, Lawrence J. ...	2.C.M.	"
Blackwell, Charles W. ...	2.C.	London
Cooper, Cedric B. J. ...	2.C.	"
Dolling, Hector F. H. ...	2.C.	"
Honess, Herbert L. ...	2.C.	"
Stephen, James R.	2.C.M.	"
Stacy, Alfred E. F. ...	1.C.M.E.	"
Brown, Dudley R.	2.C.	Southampton
Beattie, Walter C.	1.C.M.E.	Glasgow
Jones, Frederick G. F. ...	1.C.M.E.	Cardiff
Juniper, Norman C. ...	1.C.M.E.	Southampton
Mills, Thomas C.	1.C.M.E.	Liverpool
Nagle, William	1.C.M.E.	Cardiff
MacDougall, Duncan ...	1.C.	Glasgow
McMurray, Samuel H. ...	1.C.	"
Blackstock, Duncan ...	1.C.M.	"
Edwards, Lewis	1.C.	Cardiff
Pugh, Cyril D.	1.C.	"
Andrews, Alfred R. ...	2.C.	"
Bennett, Stanley G.... ...	2.C.	"

Name	Grade	Port of Examination
Reid, William	1.C.	Leith
Macintosh, James L. ...	2.C.	,,
Manson, James	2.C.	,,
Simpson, David	2.C.	,,
Urquhart, Francis ...	2.C.	,,
Hughes, Thomas W. ...	1.C.	Liverpool
Jackman, Arthur W. ...	1.C.	,,
Ramsay, James W. ...	1.C.	,,
McClintock, Henry B. ...	2.C.	,,
Parkinson, James	2.C.	,,
Sessions, John H. L. ...	2.C.	,,
For week ended March 31st, 1932:—		
Snaddon, Andrew	1.C.	London
Hogg, Roy S.	2.C.	,,
Hollingum, Richard J. ...	2.C.	,,
Nicol, Mackie William R....	1.C.M.E.	,,
Davidson, Charles A. ...	1.C.M.E.	,,
Hall, Robert	2.C.M.E.	Newcastle
Crossley, George B. ...	1.C.M.E.	Liverpool
Aves, James E.	1.C.	Sunderland
Byers, Harold	1.C.	,,
Gillespie, William R. ...	1.C.	,,
Cutter, Lancelot G. ...	2.C.	,,
Hastie, Leslie D.	2.C.	,,
Pace, George A.	2.C.	,,
Dale, William R.	2.C.M.	,,
Forster, Edward W. ...	2.C.M.	,,
Waugh, Harold	1.C.M.E.	,,
Grace, Cornelius M. ...	1.C.	Liverpool
Haste, Thomas W.	1.C.	,,
Long, Gordon J.	2.C.	,,
Starkey, William	2.C.	,,
Butcher, George F.	1.C.M.	,,
Frew, Harry	1.C.	Glasgow
Wilson, George E.	2.C.	,,
Kirkpatrick, David ...	2.C.M.	,,
Brown, Ernest	1.C.	Newcastle
Cleghorn, George	1.C.	,,
Mitchell, John	1.C.	,,
Davison, Gordon	2.C.	,,
Stonehouse, Robert W. ...	2.C.	,,
Tuck, Edward A.	2.C.	,,
Macdonald, Thomas ...	1.C.	London
Simmons, Harold J. ...	1.C.	,,
For week ended April 7th, 1932:—		
Cooke, William J.	1.C.	Liverpool
Corlett, George F.	1.C.	,,
Evans, Reginald	2.C.	,,
Smith, George F.	2.C.	Leith
Aldis, Cecil E.	2.C.	Southampton
Westley, Thomas C. ...	2.C.	,,
Jarvie, Joseph D.	1.C.	Glasgow
Bargh, John	2.C.	,,
Chisholm, Simon F.... ...	2.C.	,,
Jamieson, George MacD. ...	2.C.M.	,,
Brown, William V. ...	1.C.	London
Rae, Andrew B.	1.C.	,,
Taylor, Hugh E. P.... ...	1.C.	Belfast
Carson, Henry	2.C.	,,
Grainger, Thomas W. ...	2.C.	,,
McGarry, John	2.C.	,,
Longworth, James	2.C.M.	,,
Powell, James H.	2.C.	Cardiff
Wise, John R. G.	2.C.	,,
Naylor, Alfred E. ...	2.C.M.	,,
Ridley, Henry	2.C.	Newcastle
Palmer, William J. ...	1.C.M.E.	Cardiff
Rogers, William G. ...	1.C.M.E.	,,
Simpson, David B.	1.C.M.E.	Leith
Brown, Alexander B. ...	1.C.M.E.	Liverpool
Mitson, Walter A. ...	1.C.M.E.	London
McGinity, Andrew ...	1.C.M.E.	Belfast

ADDITIONS TO THE LIBRARY.

Purchased.

Scientific and Industrial Research. Grants to Research Workers and Students, Notes on. (revised January, 1932.) Published by H.M. Stationery Office. 2d., post free 2½d.

Merchant Shipping (Safety and Load Line Convention) Bill. The (H.L.) Commons Amendments. Published by H.M. Stationery Office. 1d., post free 1½d.

Merchant Shipping (Safety and Load Line Convention) Bill. (Lords) Standing Committee B. 1st Day's Proceedings, Feb. 11th, 1932. Published by H.M. Stationery Office. 6d., post free 7d.

King's Rules and A.I. Amendments (2/32). Published 1932 by H.M. Stationery Office. 2d. net.

Universities Year Book, 1932. Published by G. Bell & Sons. 15s. net.

Statutory Rules and Orders, 1932, No. 96. Merchant Shipping. The Load Line Rules. March 17th, 1932. Published by H.M. Stationery Office. 1s. 9d., post free 1s. 10d.

Statutory Rules and Orders, 1932, No. 108. Merchant Shipping. Safety—The Load Line. (Particulars of Depth Loading, etc.) Regulations, March 17th, 1932. Published by H.M. Stationery Office. 2d., post free 2½d.

Presented by the Publishers.

British Standard Specification No. 4-1932. Dimensions and Properties of British Standard Channels and Beams for Structural Purposes. (Revised March, 1932.) Published by British Standards Institution. 2s. net, post free 2s. 2d.

Nickel Bulletin on "Heat Resisting Alloys", Published by The Mond Nickel Co.

Nickel Bulletin on "Nickel Bronzes". Published by The Mond Nickel Co.

Bulletin No. 35 on "The Preparation of Cyclopopyl Cyanide and Trimethylene Chlorobromide", and "The Effect on Wool of Temperature and Hydrogen Ion Concentration of the Scouring Bath". Published by Rensselaer Polytechnic Institute, U.S.A.

Circular No. 26 on "Economic Attitudes in Industry". Published by The Ohio State University, U.S.A., March, 1932.

Metallurgical Abstracts. Published by The Institute of Metals, 1931.

"The Air Resistance of Ships' Hulls with various Types and Distributions of Superstructures". Paper read by G. Hughes, B.Sc., before The Institution of Engineers and Shipbuilders in Scotland. (Presented by The National Physical Laboratory.)

"An Investigation of the Performance of Gears". Paper read by J. H. Hyde, G. A. Tomlinson and G. W. C. Allan before the Institution of Automobile Engineers.

Presented by the Author.

"Internal Combustion Engines". Paper read before the Chelmsford Engineering Society by A. C. Yeates.

"The Marine Steam Turbine". 7th Edition, by J. W. M. Sothern. Published by Crosby Lockwood and Son. 40s. net. 994 pages.

A text-book which runs into its seventh edition has proved its worth. The author has made a valuable addition to his book with a full description of the steam turbine auxiliary drive using hydraulic, spring and electric coupling to the propeller shaft.

The turbine electric drive as the main propelling machinery is introduced, but this important development in marine propulsion is treated only by a meagre descripton of the machinery of the "Strathnaver".

Steam pressures have been rising since the steam boiler was first used, and the author details the progress made in this direction with pressures up to 550lb. per square inch, and contemplates that even higher pressures may be used in the near future. This latter statement should be accepted with reserve, because the highest pressure which can be used economically is still in doubt. The total heat of saturated steam is only slightly increased by raising the pressure about 550lb. per square inch, and Callendar stated that he "could see no advantage in going beyond this pressure".

"Creep" in superheater tubes at high temperatures is dealt with on page 795, but we consider the author errs in brevity in dealing with a subject which bars progress in the use of high temperature steam.

The book, with its descriptions of all classes of turbines, numerous sketches and photographs, and the results of complete tests on turbine machinery, is excellent for reference, but its bulk reduces its value as a student's text-book. It contains much extraneous matter not relevant to its title, and the sections on oil fuel burning, water tube boilers, electric accumulators and many other parts of the machinery, although providing useful information, are far from complete and should be moved to their proper sphere. T. A. B.

Benevolent Fund.

The Committee gratefully acknowledge receipt of a donation of 8s. 6d. from W. A. Tait, Member, Dundee.

JUNIOR SECTION.

Steam *versus* Diesel Machinery for Marine Propulsion.

A debate on the above highly controversial subject was held at the Institute on Thursday, March 10th. The meeting was under the able direction of Eng. Lieut.-Com. H. S. Humphreys, Member of Council, who officiated as Chairman.

The debate was opened by Mr. H. R. Tyrrell, B.Sc., Associate, who presented the case for steam, being followed by Mr. E. W. Cranston, Wh.Sc., Graduate, on behalf of diesel machinery. Mr. Tyrrell arrived at a (to him) conclusive decision by a cleverly reasoned and unquestionably fair statement of the case for steam installations, in which he marshalled a series of convincing examples of economical and reliable steamship performances, mostly of high-powered vessels of post-war design. Although he devoted but brief attention to the highly important factor of fuel consumption, he did not ignore it, but, to his own satisfaction at least, he effectively "spiked his enemy's guns" on this issue by skilfully using some unquestionable facts as evidence of the ultimate all-in superiority of the steamer even as regards fuel economy. Whatever impression Mr. Tyrrell's discourse may have created on individual listeners as affecting their views on the subject at issue, it seems safe to assume that there could have been nothing but unanimity as regards his ability as a debater. The presentation of his case was listened to with evident delight by the whole audience.

Mr. Cranston provided a contrast in method of approach to the subject, in that he concentrated on comparative performances of steam and diesel vessels expressed in cold figures relative to fuel consumption, maintenance, repair and running costs taken from actual vessels over varying periods of service, including some of the earliest motor ships with Burmeister & Wain four-stroke engines. The cases put forward by both speakers, particularly Mr. Cranston's, were inevitably lacking in conviction to some extent due to the fact that any figures quoted were obtained under special circumstances, mostly on trial runs, often, apparently, with the ulterior motive of propaganda, rather than from a disinterested disclosure of all-in running costs over long periods. By this criterion it seems that every similar debate on the rival systems of marine propulsion must fail to result in a decisive verdict of real value to any shipowner (if such there be) entirely independent in his choice of fuel. By reason of the copious figures he employed, Mr. Cranston's attack was possibly easier to parry owing to his reliance upon the authority of the technical Press, as compared with Mr. Tyrrell's safer tactics based on accepted facts culled from more widely known steamship performances.

On the debate being thrown open to the meeting a brisk discussion ensued, in which Messrs. L. E. de Quidt, J. H. Williams, E. R. Hall, J. H. Graves, W. A. Christianson, J. Calderwood, A. F. C. Timpson and the Secretary participated. A majority of these speakers appeared to favour diesel machinery, though it was evident that nearly all were still open to conviction from either side. The same indeterminate state of affairs was confirmed during the following proceedings, which included a summing up by the two openers of the debate, and ultimately a motion put to the meeting by the Chairman, that "in the opinion of this meeting steam engines are more beneficial to the shipowners for propulsion than diesel engines". On a show of hands being taken 15 voted for the motion, 8 against, whilst over 30 members of the audience refrained from voting.

On the proposal of the Chairman hearty votes of thanks were accorded with acclamation to Messrs. Tyrrell and Cranston, and on the proposal of the Secretary a further enthusiastic vote of thanks was passed to the Chairman for his excellent conduct of the meeting. B. C. C.

The Salvage of the Ex-German War Vessels at Scapa Flow.

A most interesting lecture was delivered to a crowded meeting under the auspices of the Junior Section at the Institute on Thursday, March 31st, by Mr. E. F. Cox, of the famous salvage firm of Messrs. Cox & Danks. The subject was the salvage of the ex-German war vessels at Scapa Flow. Mr. T. R. Thomas, B.Sc., occupied the chair.

The lecture took the form of a fascinating talk, during which Mr. Cox described the stupendous difficulties he had to overcome in raising the 26 torpedo boats and destroyers and two battle cruisers of the sunken German Fleet from the ocean bed at Scapa Flow.

The job occupied seven exciting, dangerous years and cost £450,000, the profit working out at about £10,000 only, but listening to Mr. Cox's breezy narrative one might have imagined this gigantic task had been a holiday for him.

The audience, however, knew that for seven years he had lived at Scapa Flow out of touch almost with civilisation, taking his meals in a little cabin on the salvage ship, all the while responsible for the lives of 70 or 80 men who would have been drowned like rats had he made a slip.

"When you hear the figures of what it cost me", he said, "you will say that I am a bigger fool than I look. Before commencing the job I had never done anything of the sort. My previous work had been breaking up battleships".

It was a Danish friend who first suggested the salvage work in Scapa Flow. He and his wife went over to the place and he reached his decision after a 24-hours' visit. "If I had spent more than 24 hours there", he said, "I should never have started it, I suppose. I made a lot of mistakes during the job, but nothing worth doing is accomplished without mistakes".

Before they lifted the first ship they had spent £40,000 in equipment, etc. He purchased a submarine floating dock from the Admiralty, cut it in two and moored the two halves of the dock over the boats he proposed to raise. The method was to pass chains under the sunken ships, wind the wrecks up from the bottom of the sea towards the surface and then tow them into shallow water.

The first check came when the cable chains snapped. "We ran like the Dickens", he said laughing, "but happily not a man was hurt". After some delay steel ropes were secured to take the place of the chains, but there were risks at every turn, at first. Sometimes the dock side tipped down, and he wondered what would happen if a rope broke.

It took ten working days to raise the first destroyer, and 25 were raised in three years. Each presented a fresh problem, as they lay in different positions, but it was an entirely new proposition to jump from a 750 ton destroyer to raising the mighty 25,000 ton battleship, the Hindenburg. His method here was to seal up the openings in her sides, close the valves which the Germans had opened, pump out the water and so render the vessel buoyant once more.

"We had 15 divers", he said, "and they put in all 800 patches on the various openings. That cost a lot of money. One big patch alone cost £500".

"The divers did wonderful work", he said. "Remember we had no plans of the interior of the great ship, and it requires a lot of pluck and nerve to go down into the filthy darkness and carry out this highly skilled work.

"We used about 40 pumps on her altogether, and you will guess the excitement we felt when at last the ship began to move from the bottom. It was soon after this that she started her funny tricks".

Mr. Cox went on to describe how the Hindenburg began to heel over; the floating dock tilted to a terrifying degree, and when he saw the huge bulk was likely to overturn he gave the order to cease pumping, and she was allowed to sink to the ocean bed again.

An immediate difficulty, he continued was that as the nose of her lifted, the water rushed to the other end of the vessel where there were no pumps. While they were moving the pumps, the vessel began to fill again.

For a time he turned his attention to other battleships, and with them he had success. Determined not to be beaten, he made a fresh start with the Hindenburg, but it was not until he had spent £50,000, and had her supported on either side by 500-ton blocks of concrete, that he succeeded in his task. In September, 1930, the largest ship ever salved from the sea-bed in the world's history was on her way to Rosyth.

Twenty-five destroyers and seven battleships and cruisers were raised in seven years.

Mr. Cox has a wonderful record of salvage work, and it was only the other day that his expert knowledge and advice was called upon for the raising of the submarine M2. Even if the firm disappears, Mr. Cox's profound experience will remain available in the event of fresh salvage problems presenting themselves.

At the close of the meeting hearty appreciation of Mr. Cox's extraordinarily interesting narrative and of his exceptional abilities as a lecturer was expressed in a vote of thanks, which was carried with acclamation on the proposal of the Chairman.

Editorial Note.—Abstracts.

Owing to the extent of other matter, it has been necessary to omit the usual Abstracts from this month's issue of THE TRANSACTIONS.