7.

PULVERISED FUEL.

Introduction.—One of the most striking developments of the past decade has been the vast increase in the use of petroleum products, and, although expert investigations indicate that sufficient stores of crude oil exist within the earth to provide for even greater demands over a considerable period, it is evident that such inroads upon the world's stock of fuel should not be permitted to continue unchecked, especially in view of the uncertainty which exists regarding the exact extent of the available supplies.

Oil suitable for fuel purposes can be, and is, produced in appreciable quantities from the oil-bearing shale deposits which exist in profusion in many parts of the world. In this respect, the United Kingdom is not too happily situated, as the majority of the sulphur-free shales have to be mined at considerable depths, thus adding greatly to the cost of production; the more easily worked deposits, on the other hand, are characterised by so high a sulphur content as to render them unsuitable for burning under boilers unless some method of freeing them from this impurity can be discovered. In the United States, however, enormous surface deposits of excellent quality shales occur, principally in California, and it has been stated that the production of shale oil will eventually exceed the coal output in that country. It is of interest to note that portions of the deposits referred to have been specifically earmarked as the oil fuel reserve for the United States Navy.

The mere suggestion of a shortage of oil has been sufficient to turn the minds of engineers and scientists towards the discovery of alternative fuels, which, while possessing the advantages of oil should also exist in vast quantities, or, better still, be capable of being manufactured from renewable products of the earth, such as growing vegetation.

One obvious direction in which to direct research is that of the production and economical employment of alcohol, which can be manufactured readily from grain, roots, &c. The use of this fuel may, no doubt, become general in the future, but its present development is hedged about with difficulties both technical and fiscal. In spite of this, however, considerable progress is being made, notably in Australia, and under Japanese control. Vast stores of coal still exist in the earth, and the depletion of these has lately been on a decreasing scale owing to the rapid extension of the use of petroleum oils, and the increasing use of water power, the main factors determining the change from the one fuel to the other being the ease of handling, increased efficiency in use, and the reduced size of the generating plant, made possible by the use of oil.

It is evident, therefore, that if methods can be developed whereby the handling of coal can be made more simple, its use more efficient and more easily or automatically controlled, and its combustion satisfactorily effected in boilers comparable in size to those employed with oil fuel, then not only will the world-supply of oil be conserved for a longer period, but also, a most important factor from the British point of view, the balance of trade will be affected in our favour.

The existence of large supplies of inferior coal and of coal dust in certain areas adjacent to the pit heads resulted many years ago in attempts being made to burn this material under steam boilers. A measure of success attended these early experiments, and coal dust, or, to employ the modern term, pulverised fuel, has been in use in such localities for a considerable period, but only in small plants. The general rise in the cost of fuel during the latter part of the late war directed attention anew to the possibilities of making use of such waste (and therefore cheap) fuel in the boilers of large power-stations, and it was not long before full scale experimental plants were in operation in the United States, a country ever eager to try out new ideas.

It was found to be a comparatively easy matter to obtain satisfactory burning of the fuel once the requirements of fine pulverisation and adequate mixture of the air and fuel had been provided for, but the principal practical difficulty which had to be overcome was the great length and size of the combustion chamber necessary for maximum efficiency. It was soon realised that in the combustion of pulverised fuel, as with oil, a time factor was involved, rendering it necessary to keep the dust in contact with the requisite air for a period sufficiently long to enable the burning to be properly completed before the fuel comes into contact with comparatively cool surfaces. Coarse, improperly dried fuel and poor admixture with the air were found to be factors which retarded combustion and thus led to the great length of flame, which is a characteristic of the majority of the present pulverised fuel installations.

The size of furnace is not so important in power station work as it is in marine practice, but, as this forms an appreciable factor in the capital cost of the plant, much time and thought is now being expended with a view to increasing the quantity of the fuel which can be burned in a furnace of given volume and of restricted length. Progress in this respect was first pursued in the direction of obtaining finer pulverisation and in heating the air supply, and these specifics have been found to effect an appreciable improvement. A marked advance has, however, been made during the past twelve months, principally due to the introduction of new types of burners which, by increasing the turbulence of the stream of air and coal dust, have enabled the length of the flame to be cut down from 20 feet or more to one of 5 to 7 feet, a figure comparable with that obtained with oil fuel: the maximum quantity of heat hitherto released in a given furnace has, however, not exceeded about one-half that usual in highly forced Naval boilers burning oil fuel, and this is no doubt partially due to the comparatively low calorific value per cubic foot of the coal dust.

Coal, unlike oil, contains an appreciable percentage of ash, an average figure being about 10 per cent., even after the sample has been carefully screened and washed. The ash is necessarily pulverised and fired into the furnace with the coal, and the resultant effect depends largely upon the melting point of the ash and upon the temperature of the furnace. In the case of an ash whose melting point is below the furnace temperature, a slag is formed and deposited upon the walls and floor of the furnace where, if of suitable composition, it fluxes the brickwork and causes rapid deterioration of the latter; slag may also be formed upon the tube and furnace surfaces, impeding the flow of the furnace gases and interfering with the transference of heat: similar effects will be experienced if the burning particles of fuel meet these comparatively cool surfaces before combustion is complete. It is to be noted that coal ash is not homogeneous, but consists of a mixture of from three to five entities, one of which, while possibly only present in small quantities, may possess a low melting point. A constituent of this nature may thus well render a fuel unsuitable for use in the pulverised form, while giving complete satisfaction in a chain-grate or other mechanical stoker.

The wear and tear of the furnace linings in plants of this type is, in general, greatly in excess of that usual in oil-fired boilers, but may be much reduced by the use of fuels with ash of high melting point, by avoiding high flame velocities and by careful control of the furnace temperature. The latter remedy is, however, uneconomical, as for efficiency the maximum possible temperatures should be employed, and attention has therefore been called to the necessity of discovering refractories which would withstand the action of the slag. It appears, however, that but little success has hitherto attended this search, with the result that the modern tendency is to replace the brick linings by heating surfaces, thus not only avoiding the heavy cost of frequent renewal of the former, but also actually improving the efficiency of the boiler, as by this means a greater proportion of the total heat transfer is effected at the maximum temperature in the cycle.

The difficulties attendant upon the use of these so-called "water walls" in boiler furnaces have not so far proved to be formidable in power-station work, as sufficient circulation can be provided under steady steaming conditions. The situation is, however, not so favourable in boilers subject to wide fluctuations in steam demands, and at least one case is known where burning out and pitting of the water wall tubes has been undesirably frequent, the defects being attributable to insufficiently good circulation: for this reason boilers of this type do not appear suitable for Naval purposes unless separate feed supplies, under reliable automatic control, can be provided for each header which feeds the tube walls.

The difficulties with the furnace linings appear, however, to have been very greatly reduced by the use of the modern short flame burners, in which the intensely heated zone is localised and combustion is completed before the " flame " can strike cool surfaces.

The quantities of ash and slag formed during combustion are in general more readily removed than in the case of stoker fired boilers, as in cases where pulverised fuels of low and suitable ash content are used practically the whole of this residue should be discharged up the funnel, leaving but small quantities to be cleaned out of the ash pits. This is especially the case when considerable quantities of excess air are used, as by this means not only is the furnace temperature kept low enough to prevent melting of the ash, but also the high speed gas currents prevent deposition of the latter : thus convenience may be purchased at the price of some loss in efficiency. In other cases, however, conditions may be less favourable and special provision for ash handling is required. Generally speaking, however, it appears that the plant and labour required for this purpose is considerably less than in stoker fired boilers, the ash being finer and smaller quantities require to be handled : the heat lost in the ash is frequently recovered in part by arranging that the hot ashes traverse water-cooled tubes during their passage to the ashpits. In comparison with oil fuel, however, it is evident that the ash problem involves additional plant and labour, while more frequent cleaning of the heating surfaces is required : it has been stated that in one particular installation the amount of external cleaning approximates to that required with stoker-firing, but this obviously will depend upon the type of coal employed.

Pulverised fuel containing very large percentages of ash can be burned, while the presence of this incombustible material is to some extent beneficial as it tends to lessen the risk of explosion. It must be remembered, however, that the ash not only lowers the calorific value of the fuel, but also involves unproductive work in the pulverisers, and thus it is desirable to keep it to a minimum for marine services.

It may be of interest to note that in one large station arrangements are made so that the ash accumulates upon the floor of the furnace, where, in this instance, the temperature is kept sufficiently high to prevent solidification. The ash is tapped off in a fluid condition at suitable intervals and is directly available for certain revenue-producing uses. It appears that with proper construction of the floor and side walls at the slag line no serious maintenance problems are involved. Such an arrangement is, however, ill suited for marine purposes.

Fire and Explosion Risk.—The use of pulverised fuel has been attended by a number of fatal accidents, which have led to the publication and acceptance of somewhat exaggerated reports regarding the danger of the fuel.

The U.S. Bureau of Mines have fully studied this question and have issued a report dealing with the occurrence and prevention of fires and explosions in pulverised fuel plants for land stations.

It appears to be definitely established that the fuel in bulk is not explosive, only becoming so when stirred into a cloud with sufficient air and brought into contact with a naked flame or body hot enough to cause ignition. When stored in bulk the fuel is partially aerated, but the quantity of air included therein is but a very small fration of that required to support combustion, and thus from this point of view storage appears to be safe.

The fuel is, however, liable to spontaneous combustion, this being particularly the case when heated : the report referred to above states in fact " that spontaneous combustion is practically certain if the temperature of dry pulverised coal is kept at or about 150°F., and if the heat insulation is perfect."

Spontaneous combustion is impossible in a properly sealed bunker completely filled with the fuel, as there is insufficient oxygen present to support the action, but considerable danger would arise when attempts were made to use fuel heated to a high temperature, as fires would occur in the system conveying it to the boilers.

In view of these difficulties, it has been recommended, and in many cases has become the practice, that the quantities of powdered fuel kept in store should be cut down to a minimum not exceeding 48 hours supply : preferably pulverising should be effected immediately before use, or on what is known as the UNIT, as opposed to the Bulk-storage system.

It may be noted that an atmosphere laden with coal dust may be extremely dangerous, the risk being proportional to the finess of the particles, thus an escape of pulverised fuel can readily give rise to an explosive mixture and requires to be treated with the same respect as an escape of coal gas. Fuel systems should be entirely safe as long as the joints remain dust-tight, and though this condition should not be difficult to attain, the risk in this respect is greater than in the case of a leak of oil fuel as coal dust which has settled on a beam or in a pocket may easily be blown off in the form of a cloud which may explode. It has also been observed that a train of coal dust will burn slowly without any visible combustion, the advance of the heated zone being at the rate of some 6 inches per hour : if conditions are favourable such an action may easily result in a flame or an explosion.

In passing, it may be of interest to note that many fires and explosions have occurred in powdered coal systems due to the fuel banking up behind obstructions, bends, &c., in the main conveying it in the presence of heated air to the furnaces : the remedy is to design such ducts so as to avoid pockets and obstructions, and to blow them through with air when working is completed.

In many shore installations the fuel to the boilers is carried by air around a circulating main, tapped off for the various burners at a number of points, the surplus fuel being returned to the ready use bin: the circulating or primary air is usually heated and, owing to local variations in the density of the mixture in the main, explosive proportions may exist at various points. Secondary supplies of air enter the stream at the burners and should the pressure in the main line at any time drop below that of the secondary supply, there is a distinct tendency for burning fuel to be drawn into the main from the furnace by the reversed air flow; the danger from such a source is obvious.

Burners.—There are at present on the market a number of different types of burner, and it is probable that with suitable furnace arrangements there is little to choose between them as regards boiler efficiency.

These fittings may be classified in two groups, namely, the older type, giving a so-called "stream line" flow, and those in which efforts have been made to obtain the utmost turbulence of the mixture of coal and air as is done in oil fuel burners. The former class are characterised by the extremely long flame, often reaching 20 feet in length, while that produced by the latter is short and combustion very rapid and local. The fuel supplies to the burners may be provided either by means of screw conveyers or by heated primary air, the air required to complete combustion being added directly in the burner.

Pulverisers.—It is by no means uncommon at the present time to pulverise the coal so that at least 85 per cent. will pass through a 200 mesh, while in many plants an even finer degree of grinding is employed, with a corresponding shortening of the flame.

The grinders or pulverisers differ in design, but the general idea of all types is to remove the ground product as early as possible, passing it through a screen: this is essential, as unless the grinding surfaces are kept clear of the pulverised fuel their efficiency will be impaired, while the power required will be considerably increased. There is evidently a field for experiment as regards the design of pulverisers, the weight and power requirements for which are probably susceptible to considerable improvement.

Magnetic and other separators are invariably fitted to pulverising mills in order to remove iron or other foreign bodies in the coal and so prevent damage to the grinding surfaces.

PULVERISED FUEL FOR NAVAL SERVICES.

It may be of interest to know that a powdered coal plant was installed in 1901 at Portsmouth Dockyard in order to consume the dust and small coal unsuitable for use in stoker-fired boilers. This plant proved to be unsatisfactory in service and the matter remained in abeyance till the year 1912, when further experiments were carried out, this time at Devonport Yard, where a Bettington boiler was fitted with arrangements for burning powdered coal: this boiler is still in use and has performed its required services with reasonable results. The plant at Devonport is, of course, of very early design and some difficulties are met with in lighting up the boiler, while certain types of coal (notably those in which the volatile content is below about 11 per cent.) cannot be burned at all by themselves.

During the War the shortage of oil tankers, due to the submarine campaign and to the enormously increased demands for oil fuel, resulted in earnest consideration being given to all possible methods whereby coal might be used to relieve the situation. Experiments with pulverised fuel were carried out in the U.S. and in Australia in 1918 in small marine installations, and these indicated that while it was practicable to burn the fuel, there were many problems to be solved before it could be successfully applied to marine purposes. The investigations were, however, of value in enabling a just appreciation to be formed regarding the possibilities of the fuel for Naval purposes, and it is with these that the main part of this paper is concerned.

Bulk of fuel for a given "Heat" stowage.—The table given below gives a comparison between various fuels as regards the potential quantity of heat that can be stowed in a given space. It must be realised that the figures given are only averages, and will vary with individual samples; further, the comparison of coal with oil is somewhat less favourable in practice than that shown by the table, as it is possible to utilise compartments of irregular shape to better advantage with the latter fuel than with coal:—

Fuel.	Cubic Feet per ton.	Calorific Value B.T.U./lb.	Comparative Heat Stowage per cu. ft.	Comparative Evaporative Power per cu. ft.
Oil fuel - -	38	19,000	100	100
Coal - -	52	12,500–15,500	48·1–59·6	39–48·6†
Pulverised coal -	48	12,500–15,500	52·1–64·6	52·1–64·6*
Pulverised L.T. coke - -	51	12,500–14,500	49·1–56·9	49·1–56·9*

* Assuming equal combustion efficiency to oil fuel.
† Assuming 18½ per cent. less combustion efficiency than with oil fuel.

The figures given for the number of cubic feet required for the stowage of one ton in the cases of the pulverised fuel depend upon the degree of aeration, and thus upon the time which has elapsed since grinding and upon the subsequent treatment of the fuel, but are probably fairly representative of the condition obtaining when the fuel is delivered from the mills; the comparison is, however, favourable to these fuels.

It will be observed from a consideration of the foregoing table that, in order to provide a given radius of action, the fuel stowage capacity will require to be nearly doubled if pulverised fuels are substituted for oil. This fact is an inherent handicap upon those fuels and obviously constitutes one serious obstacle to their employment in the British Navy.

The position as regards this factor of fuel stowage is, however, much less unfavourable in the Mercantile Marine, for, although no shipowner desires to devote unduly great space for bunker purposes, this may be of lesser importance under certain conditions than the cost of operation.

It has been shown, to the satisfaction of the enthusiasts at least, that a substantial saving is to be anticipated by the change from hand-fired boilers to pulverised fuel equipment, but it yet remains to be demonstrated whether the additional capital cost and increased maintenance charges will be outweighed by the increase in boiler efficiency, by the possible reductions in the personnel required for operating the plant, and by the lower cost of the raw fuel in cases where inferior coals are pulverised. In comparison with oil-fired boilers the overall efficiency of the pulverised installation is likely to be some 5 per cent. to 6 per cent. less on account of the power requirements for handling the fuel, while the maintenance charges may well be somewhat higher on account of the wear and tear of the pulverising plant; on the other hand, the cost of oil fuel is about two to three times that of pulverised fuel, and thus there should on balance be a financial saving due to a change to the latter.

Production, Storage and Handling of Pulverised Fuel.

Method I.—Supply to ships in pulverised form.—The production of dry pulverised fuel necessitates the provision of power, and from the point of view of overall economy this is best applied at the mines (or other convenient place) to large quantities of the fuel rather than locally at the boilers. In marine installations not only will there be an economy in fuel by providing this in the pulverised state, but there will also be a reduction in the weight, space and complexity of the plant required to be carried on board each vessel.

It has been pointed out earlier in this paper that the storage of dry pulverised coal for any length of time is unsafe, especially in bunkers adjacent to heated surfaces such as are common in steamships. It has been stated, however, that low temperature carbonised coke is not liable to spontaneous combustion when pulverised, and this, should it prove to be correct, points to one method of avoiding the danger referred to. It is also not impossible that some system of storage in an atmosphere of inert gases may prove to be practicable, but, as the safety of such systems depends upon the maintenance of the bunkers in an airtight condition, it appears doubtful whether in practice their effectiveness could be relied upon. Even if safety is assured, however, there still remains the enemy of moisture which may entirely prevent the handling of the fuel or at least will interrupt that steady flow which is essential to proper combustion. The maintenance of bunkers in a thoroughly dry condition hardly appears to be a practicable proposition and it remains to be proved by trial whether the effect of unavoidable moisture can be accepted.

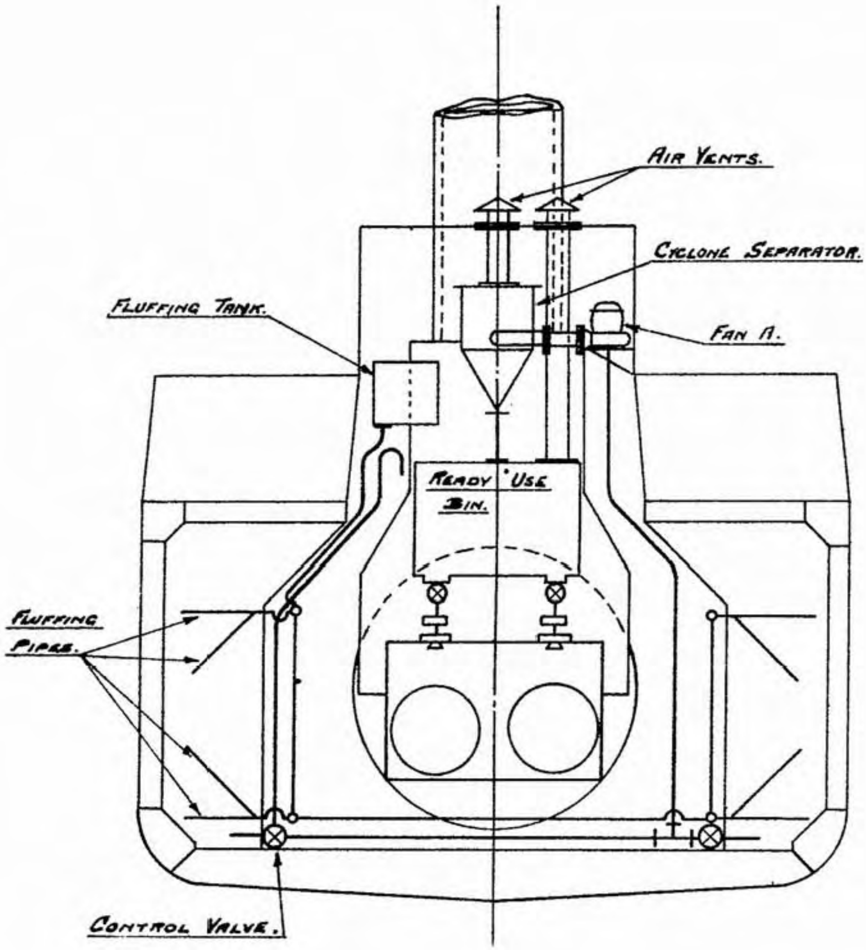
Another solution put forward is to seal the bunkers with exhaust steam, but this is clearly impracticable for marine work in view of the waste of fresh water, while the consequent moistening of the fuel would lead to difficulties in obtaining a smooth and even flow of the fuel to the burners.

The storage ashore and subsequent supply to ships of coal in the pulverised form is, however, attractive from the point of view of the overall economy of the complete process and of the saving in the weight and space of the machinery, and also because the problems of coaling ship and of transporting the fuel to the burners are thereby simplified, as pulverised coal or coke can be passed through pipes by means of a current of air, behaving much as a liquid.

Trials that have been made indicate that this method of handling the fuel is practicable, thus enabling an appreciable reduction to be effected in the personnel required for operating the plant. The following description is taken from a paper read by Engineer Captain Brand, R.A.N., before the Society of Naval Architects and gives a general idea of the various fittings that will be necessary :—

> The fuel is dried and ground on shore, being then forced through pipes and hoses to the vessel, the propelling agent being the flue gas from the drier, suitably cooled, and then compressed to about 40 lbs. per square inch : about 5 cubic feet of gas is required per ton of fuel.
>
> The ship end of the hose is fitted to a separator secured to the bunker lid, thus permitting release of the gas, a quantity of which is blown through the bunker before fuelling. In the case of a vessel with many bunkers it is evident that a blowing through hose would have to be supplied in addition to the fuelling hose, as the latter could not readily be used to perform both functions except for the first bunker. On completion of bunkering the lid is jointed in place and the compartment should remain air tight and therefore safe, since the interstices of the fuel are sealed with the comparatively inert flue gas.

The possibilities of danger arising appear to be two-fold, namely, the bunker in practice may not remain air tight, and secondly the flue gas used for sealing purposes may not in fact be inert, as it commonly contains by no means inappreciable quantities of air and of CO.



AIR VENTS.
CYCLONE SEPARATOR.
FLUFFING TANK.
FAN A.
READY USE BIN.
FLUFFING PIPES.
CONTROL VALVE.

FIGURE 1.

One of the most difficult problems to be surmounted was that of emptying the bunkers, as the system had to be capable of removing fuel from compartments of irregular shape and also to be completely air tight. The early attempts included both screw conveyors and suction pipes into the dust, but the former, of course, proved to be ill-adapted for use in bunkers of irregular shape, while the latter was impracticable owing to choking of the pipes.

The final solution is shown by the diagram in Fig. 1. Warm air is drawn by a fan (A) through pipes which are connected to the bunkers, in which positions suitable ports are cut in the pipes, the openings being controlled by hand from the stokehold. The fan discharges the air, together with any fuel drawn in by way of the ports, into a separator where the dust is directed by gravity into a ready use bin, while the air is released to the atmosphere. A successful type of separator, known as the Cyclone, has been evolved for purposes such as these, the air being filtered through a self clearing grid. In parenthesis it may be remarked that the conditions within a separator are favourable to explosion, as the coal exists as a cloud in air, and thus any spark or other means of ignition at this point will be certain to have disastrous results, which have indeed been actually experienced in some plants.

The evacuation of the fuel from the bunkers by this means results in the formation of a partial vacuum, and pipes, known as "fluffing" pipes, are provided whereby inert funnel gas may be injected into the bunker at suitable positions, with the dual objects of restoring normal pressure and of agitating the dust sufficiently to prevent packing. The funnel gases are extracted, cooled, compressed and stored for this purpose in a suitable container. The previous remarks regarding the possible danger introduced by the presence of large quantities of excess air in the so-called inert flue gas apply equally here, while a further hazard is introduced by the risk of poisoning from the CO which may exist in these gases: this system also demands additional plant and expenditure of power for the preparation of the gas.

The fuel is led from the ready use bins to the burners by means of a screw conveyor to which admittance is gained through a dust tight valve, operated by hand.

Connections are provided from the inert gas or "fluffing" system to various points in the ready use bin and in the fuel system in order to re-aerate the fuel after prolonged stoppage.

It has been stated by its originator that this system is no more complicated than that required for burning oil fuel, and there may be some truth in this *when it is applied to a small installation*. An extension of the method to a large vessel with numerous bunkers, however, involves considerable complication especially in view of the fluffing system, with its possibilities of introducing a poisonous gas into the compartments through which it passes.

Method II—" Unit " System.—In view of the difficulties just discussed it is apparent that marine conditions are better met by the so-called " Unit " System, in which the raw coal is supplied and stored in the bunkers, pulverising being subsequently effected immediately prior to use. This method provides the possibility of increased " heat " storage, and thus appears especially suitable for Naval purposes, provided that the ensuing disadvantages can be accepted. It has been suggested that the operation of taking on board the solid fuel may be simplified by subjecting the coal to a preliminary crushing to pass a 1 inch mesh, that is to " bean " size, in which form it can be readily blown through pipes by air pressure. This process appears to have much to recommend it, as thereby part of the work of pulverising can be done ashore, but it remains to be proved whether such a system of " coaling ship " is practicable.

It is only after the beans are in the bunkers that difficulties arise in transporting them to the pulverising mills. This may be effected simply enough in the case of bunkers adjacent to the boilers, as these may be made self trimming, an appreciable loss of storage space being associated, however, with this arrangement.

Another possible method is to instal transporters for this purpose, but such a plan could hardly be accepted for warships, as it involves the cutting of water-tight bulkheads, while, in any case, additional power would be required. It is also conceivable that some method of transferring the beans by air pressure may be developed, and this possibility appears to offer the best solution of the difficulty.

Much publicity has recently been given to the installation of a pulverised fuel plant by the U.S. Shipping Board in S.S. " Mercer," and, as this is arranged on the " Unit " system, it may be of interest to give a brief description of the plant as at present fitted. It must be realised, however, that this system is still in the experimental stage and will no doubt be considerably improved if vessels are specially built for working with this fuel.

S.S. " Mercer "—Description of Pulverised Coal Installation.

Dimensions of vessel: 9,500 tons displacement, 395 ft. by 55 ft. by 31 ft.

Built by Federal Shipbuilding Co., N.J., January, 1919.

Turbines: Curtis ten-stage single rotor, 2,500 H.P.; double reduction gears, 3,380–458–90 r.p.m.; 12 nozzles.

Boilers: 3 Scotch single ended—only 2 in use with pulverised coal.

3 furnaces, each 2 ft. 8 in. int. dia., 7 ft. 6 in. long, fitted with large tube loco. type superheater feed heater and Howden's forced draught. Working pressure 210 lbs. /sq. inch. Feed 240°F. Burners—Peabody combined fuel oil and pulverised coal. Heating surface 2,978 sq. ft. per boiler.

S.S. MERCER.

UNIT SYSTEM.

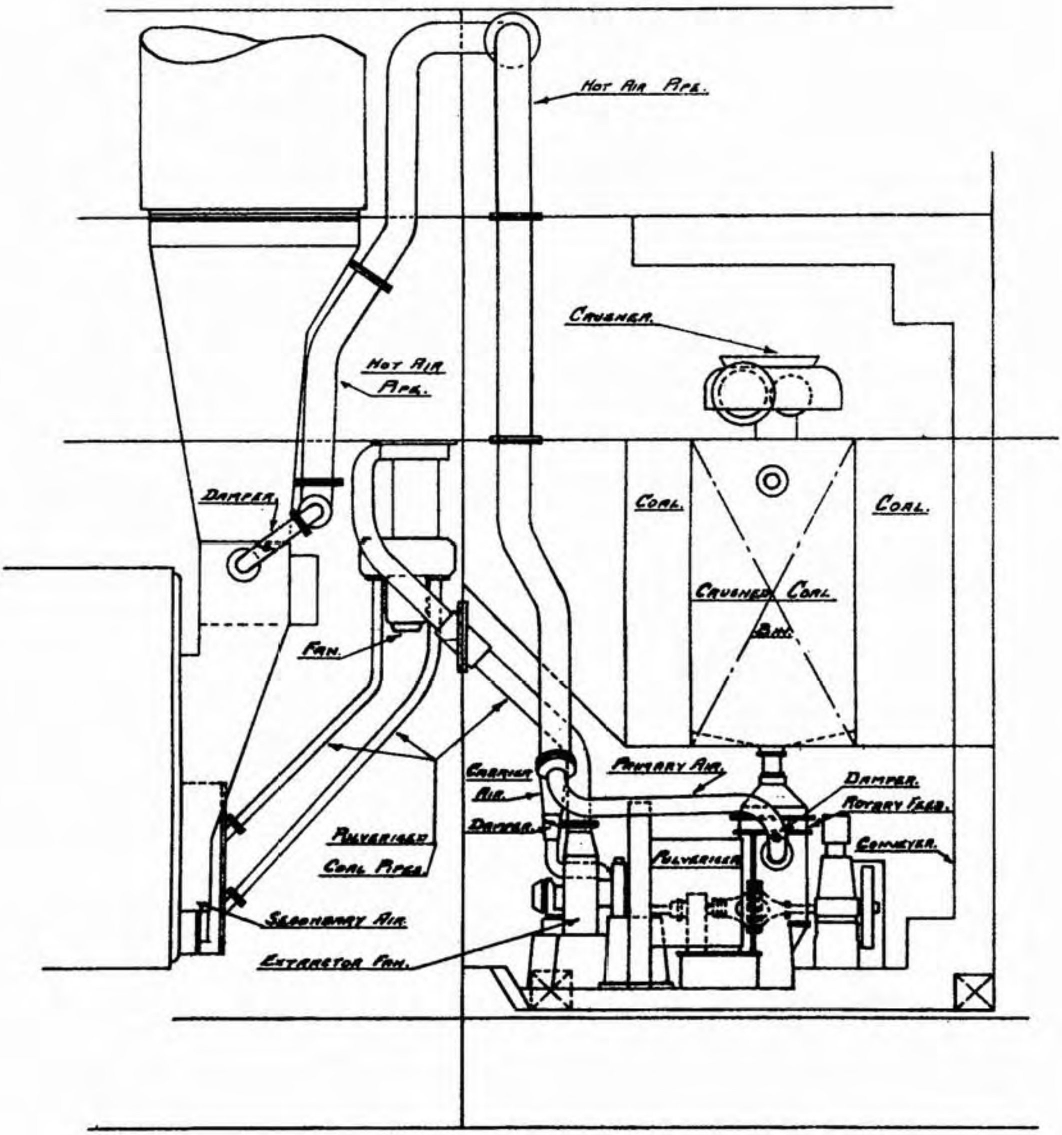


FIGURE 2.

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S. S. MERCER.

UNIT SYSTEM.

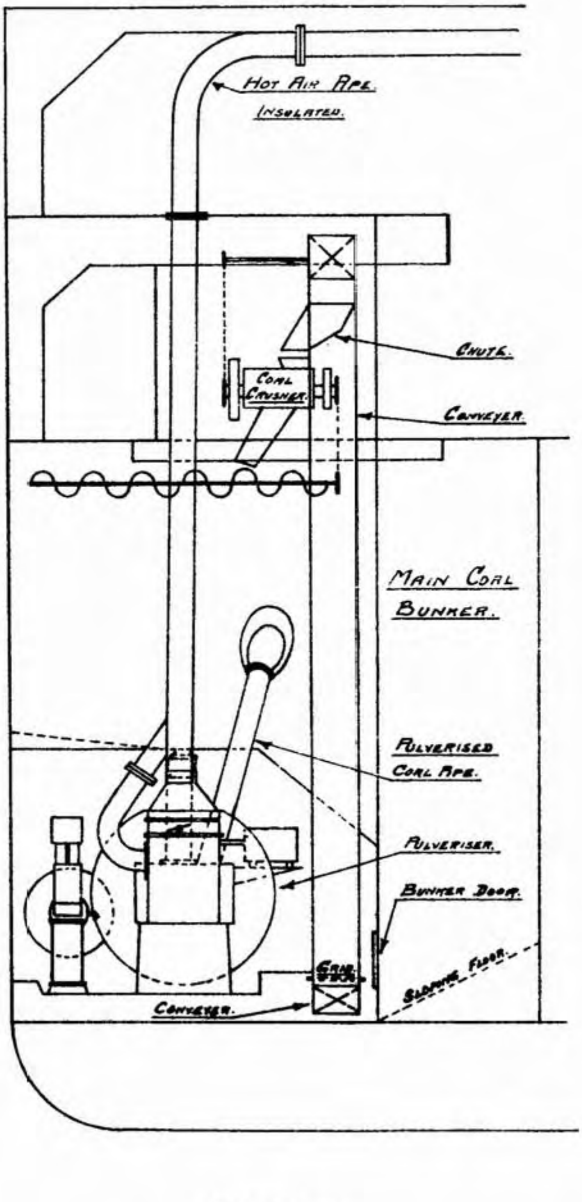

FIGURE 3.

Malby & Sons. Photo-Litho

Pulverised Coal Equipment.—Description is for one side only—the other being similar.

The main coal bunkers are arranged to give a constant gravity feed down to the bunker doors in front of the conveyor with the minimum of trimming as shown in Fig. 3.

The pulverising equipment is contained in two compartments, the crusher room and pulveriser room, each being approximately 16 feet by 10 feet by 8 feet. The crusher room is situated above the ready use bunker, the pulveriser room being below the bunker level and containing the pulveriser complete and the lower end of the coal conveyor.

The coal falls from the bunker doors through a 4 inch. mesh grating—any larger pieces being broken by hand—on to a chain bucket conveyor by which it is carried to the crusher room above, and delivered to a toothed crusher driven by a 30 H.P. steam engine. This breaks the coal to a maximum size of 1¾ in. and passes it into the ready use bunker below, capacity 20 tons; the crusher plant is employed normally about 2 hours per day only.

The coal feeds by gravity from the ready use bunker to the rotary feeder disc, spreading over this disc in a conical pile, but being prevented from spilling off it by a sheet metal guard extending a few inches above the upper surface of the disc. The guard is stationary and is cut away for about 30° of its circumference in order to admit the feeder knife, a metal finger whose function is to scrape the coal continuously from the pile on the disc into a small chute leading to the pulveriser. The position of the knife and therefore the amount of coal fed into the mill can be adjusted by a hand-wheel and thus forms one control. This so-called "slicer" disc is driven by means of a 3 H.P. variable speed electric motor and by varying the speed the necessary amount of coal is allowed to pass from the bunker into the pulveriser.

The pulveriser is a Kennedy Van Saun Air Swept Tube Mill having a drum 5 feet diameter and 8 feet long driven at 35 r.p.m. through gearing by a 30 H.P. reciprocating steam engine and containing a charge of about 5,000 lbs. of Herculite steel balls of 3, 2 and 1 inch diameter.

The balls are raised a certain height by corrugations provided on the interior circumference of the drum, and then fall upon the coal which is thus hammered to powder: a considerable amount of lagging is fitted to deaden noise.

A quantity (about 30 per cent. of the total air supply) of hot primary air at about 180° F. and ½ inch of air pressure from the Howden Forced Draught Fans is admitted at the inlet end of the pulveriser. This primary air dries and blows the finely pulverised coal in the mill towards the outlet, from which it is pumped, together with a further quantity of hot carrier air by means of the extractor fan, through a pipe leading to the boiler room: the fuel is in a state of considerable turbulence at this point.

The amount of the additional supply of hot air to the extractor fan is controlled by dampers and varies the strength of the mixture of coal and air as required.

The pulverised coal and carrier air now enters the distributor where a revolving impeller splits up any strata in the stream of coal and air and ensures a proper and even distribution of the stream to the pipes leading to the burners. These pipes are of 4½ inch internal diameter and are led tangentially into the Peabody burners from which the stream issues with a combined rotary and axial motion into the furnace. A supply of hot secondary air, averaging about 40 per cent, of the total, enters through the centre of the air register, also with rotary and forward motions, and ensures complete turbulence thus giving the necessary short flame of 7–8 feet in length.

Control of Fuel Supply.—This appears to be adequate for a tank boiler but is much slower than with O.F., and some more sensitive arrangement would have to be devised for a small-tube W.T. boiler.

The controls fitted are :—

(*a*) The "Slicer" supplying the coal to pulveriser is run by an electric motor, and the supply can easily be regulated by the speed of this motor—the normal amount of fuel in pulveriser (140 lbs.) can be cleared in about 1½ minutes.

(*b*) By slowing down the extractor fan or by regulating the supply of "carrier" air to this fan, which should be motor-driven—instead of by a steam turbine as at present.

The "strength" of the mixture of pulverised fuel and air can, of course, be regulated by the amount of "carrier" air admitted direct to the fan suction.

Control by the obvious means of shutting off individual burners has not yet proved to be satisfactory in this particular installation, as its effect has been merely to increase the fuel supply to other burners, thus necessitating further adjustment.

Safety of the Equipment.—It is considered that with reasonable care, using the "unit" system, maintained airtight right up to the burner, and pulverising fuel only as required, the danger of fire is much the same as with oil fuel, and that risk of serious explosion can be almost eliminated. Adequate steps must be taken to prevent excessive leakages of pulverised fuel and to shut off the fuel supply immediately a burner is extinguished, while the fuel must not be allowed to accumulate in the furnaces and C.C. before lighting up. It is necessary, of course, to ensure that the mill is completely exhausted of fuel on shutting down and that the whole system is blown through clear.

The pulveriser drum is fitted with a large relief valve, but it is stated that no signs of explosion have as yet been experienced at this point in Mercer's installation, nor would it be anticipated that such an explosion would be serious if the compartment outside is free from dust.

No arrangements appear to be fitted for ventilating the conveyor and crusher rooms, where a considerable amount of dust might accumulate. In shore stations the regular use of vacuum cleaners to prevent accumulations of the dust is not uncommon.

COMBUSTION AT HIGH RATES OF FORCING.

In order to achieve the combustion of pulverised fuel within the limited furnace spaces available in marine practice, the following points require consideration :—

(1) *Absence of Moisture from the Fuel.*—Before combustion can take place, any water in the fuel has to be heated to 212° F. and then evaporated, this operation not only requiring the expenditure of heat but also delaying the ignition point of the fuel and thereby lengthening the flame.

The amount of moisture to be dealt with depends both upon the type of coal and upon its treatment prior to crushing, as in many cases it is found necessary to wash the raw product in order to remove excessive dirt. In marine work it is, of course, desirable to dry the coal before delivery to the vessel, thus economising in heat expenditure on board; this is an argument in favour of bunkering the fuel in the pulverised condition: where, however, the coal is powdered at the boilers it is necessary to instal driers heated by the funnel gases, or, what amounts to the same thing, to preheat the carrier air as highly as is practicable.

The loss of heat in drying the fuel is not, however, the only drawback to the presence of moisture, as high rates of combustion can only be achieved with fine and even sub-division of the fuel, a requirement which may be adversely affected by water : rapid alterations of output are dependent also upon a ready and smooth control of the fuel, which is not possible if the dust is clogged with water.

The moisture content has also an important effect upon the power required for pulverisation, this charge upon the boiler output being appreciably less with dry coal.

(2) *Fineness of Pulverisation.*—The smaller the size of the particles of the fuel, the more readily can combustion be achieved, and this factor is thus of extreme importance for marine work and would be particularly so in Naval vessels. It appears that, other things being equal, the time required for the combustion of a powder which will pass through a 240 mesh is but one-half to one-third that necessary for a similar powder passing through a 140 mesh. This effect is due to the fact that the heavier particles maintain their velocity for a longer period, and thus pass through the highly heated zone more rapidly than will the light ones, while at the same time the latter expose to the air more surface per unit of weight than is the case with the former.

Combustion of the fuel is, of course, initiated by the finest particles, ignition of which causes the remainder to burn. It is therefore probable that for high rates of combustion the proportion and size of the smallest particles is of great importance, and that it may not be sufficient to require all the fuel to pass through (say) a 200 mesh, which from this point of view may be regarded as comparatively coarse. It appears to be the present practice in many shore stations to require all the fuel to pass a 200 mesh sieve, while in many cases over 75 per cent. will pass through 300 mesh; even finer sub-division than this may prove to be desirable at really high rates of forcing, comparable with that achieved in oil fuel T.B.D.'s.

(3) *Mixture of the Pulverised Fuel and the Air.*—The late Professor John Perry invariably insisted that the fuel, whatever its nature, must be "scrubbed with air," and the truth of his teaching has been once again forcibly demonstrated in connection with pulverised fuel.

This action of scrubbing is necessary to remove the envelope of burning gas and steam and the coating of ash which form upon the exterior of each particle of the fuel. In a pulverised fuel "flame" the particles travel normally in the same direction and at about the same velocity as the surrounding current of air, thus retarding the very necessary scrubbing referred to: an unduly long flame is the result.

Two modern developments have, however, attempted to bring fresh air into contact with the burning fuel surfaces by producing turbulence, that is by using violent air currents travelling both at higher speeds than, and in directions different to, that of the fuel stream: by so doing the time of combustion has been very appreciably reduced, from which it follows that a smaller furnace may be used for a given output.

One of these methods seeks to use the phenomenon seen in the case of a tornado, where the disintegrating effect of the centrifugal action of the air is confined to a limited area. The practical application of this principle is due to the Fuller-Lehigh Co., of Pennsylvania, and briefly consists in the injection of the fuel at, say, four points in the sides of a well which may be either square or round in section, and of which the axis may be set at any desired angle to the vertical. The jets are directed in such a manner that the centre line of each cuts the diameter of the well at a point about midway between the axis and the circumference: in this way each jet is met by two others at right angles to it, acting in opposite directions. The air for combustion may be admitted both centrally through the axis of the well and also at any desired point in the circumference, and by regulation of the supply it is possible to maintain the flame either in the well or at any desired exterior position. The published results of trials are obviously exaggerated, but it appears that an advance in the maximum heat release in a given furnace volume has been achieved with an accompanying small improvement in boiler efficiency.

The Peabody burner used in S.S. " Mercer " also embodies this idea of turbulent combustion, although not to the same degree as in the Fuller-Lehigh. The former type is supplied with fuel by primary or carrier air at a temperature of about 180° F., the arrangement of the burner being in effect an infinite number of nozzles directing the coal stream against that from a similar arrangement of nozzles, thus producing the desired turbulent or scrubbing effect. The remainder (about 40 per cent.) of the air required for combustion is supplied through secondary air ports which enter the burner on the furnace side of the nozzles : this secondary supply is similarly preheated to about 180° F. It is reported that a maximum of about 6½ lbs. of pulverised coal per hour has been successfully burned per cubic foot of combustion chamber volume in a Marine type boiler when using the Peabody burner. This is about double that recorded with the normal types of burner, but still falls far short of the requirements for Naval purposes.

(4) *Preheated Air.*—The use of preheated air has been found to accelerate combustion to a marked degree, resulting in an appreciable reduction in the burning period, and consequent length of flame. The beneficial effect of preheated air probably arises from two factors, namely, the earlier removal of the moisture remaining in the fuel; and, secondly, the raising of the body of the material to a degree nearer its ignition point, possibly causing the volatile matter in the coal to commence distillation before the furnace is reached. In this connection it may be observed that the volatile products in most coals begin to come off at a temperature of about 400° F., although occluded gases are driven out at much lower temperatures, little exceeding the boiling point of water.

It has also been found in practice that preheated air reduces the variation in fineness of the fuel as caused by moisture, and, further, the power required for pulverisation is much reduced if the operation is carried out in an atmosphere of hot air.

The preheating of the air supply by means of the funnel gases is, of course, a ready method of improving the efficiency of the boiler, as not only is the amount of waste heat thereby reduced, but also, on account of the enhanced furnace temperature, the ideal cycle is more nearly approached. This course is equally applicable (and desirable) in the case of oil-fired boilers, but, being attended by considerable demands upon weight and space, has not been adopted to any great extent in Naval practice.

A true comparison between the efficiencies of oil-fired and pulverised fuel boilers must include a due allowance for the effect of any preheating, which appears to be absolutely necessary in the latter case if the boilers are to compete as regards size with oil-fired installations : in other words, pulverised fuel boilers will inevitably be heavier, by the weight of the preheaters, than oil-fired units of the same size and effective horsepower, but may be somewhat more efficient as judged from the limited point of view of evaporation per pound of fuel. Trials carried out in Naval oil-fired boilers at low rates of evaporation have shown that preheating the air supply to only 325° F. results in an increase in efficiency of about 10 per cent., an improvement which may possibly be somewhat less at the maximum rates of forcing, when the furnace temperatures are in any case very high: this figure illustrates, however, the order of the benefit to be obtained by such means.

(5) *Quality of the Coal.*—The trials which have been hitherto made appear to indicate that the main considerations in determining the choice of a coal suitable for pulverisation for marine use are the percentage and fusion point of the ash, and the amount of volatile constituents present in the coal.

Rapid combustion is retarded to some extent by high percentages of ash, which, in any case, should be reduced to a minimum in order to avoid the waste involved in pulverising and stowing an inert substance. One report from U.S.A. states that it has been found possible to maintain combustion with fuel of 70 per cent. ash content, the boilers being started on so-called "good" fuel containing 40 per cent. ash: in this case the rate of forcing was, of course, low. The fusion point determines largely the extent to which cleaning of the boilers is necessary, and whether ash handling plant is required or not.

There is evidence to show that the suitability of coals cannot be determined solely by the melting point of the ash, as it has been found that fusion appears to depend also upon the local intensity of combustion; this is determined by factors that are not at present fully known, although the calorific value and volatility of the fuel probably exercise some effect in this respect.

The percentage of volatile matter in the coal appears to have an important bearing upon the readiness of ignition, as some coals with less than 12 per cent. of volatiles have proved difficult, if not impossible, to burn alone: on the other hand, cases have been reported in which coals containing less than 6 per cent. volatile have been successfully employed as the sole fuel in boilers, which have been lit up and operated without the use of any other material. This point, therefore, clearly requires further investigation before a definite conclusion can be reached, but it is evident that for Naval purposes, at least, it should be possible to light up boilers readily from cold and to vary with certainty the number of burners in use. Delay in ignition introduces the possibility of explosion or of spontaneous combustion in the furnaces, and is a condition which must be guarded against.

It has been shown that, apart from the foregoing factors, any coal can be burned in the pulverised condition, and, though no doubt for the highest rates of forcing the quality must be both uniform and good, it appears probable that this process will greatly extend the field from which coals suitable for steam raising in marine boilers may be drawn. It should be noted, however, that the efficiency of combustion is unavoidably affected to a varying degree by the characteristics of the particular fuel employed.

Low Temperature Coke.

A vigorous press and advertising campaign has been in progress for the past year with the object of opening up markets for the solid products resulting from the distillation of coal at low temperatures.

The following abstract from an unpublished article on this subject is included by permission of the author, and contains some suggestive information:—

"The utilisation of the coke as pulverised fuel has received considerable attention, and according to Dunn 'Pulverised and Colloidal Fuel' (Ernest Benn, Ltd.), Messrs. Edgar Allen & Co. carried out experiments in a reheating furnace with pulverised coalite ground in their own turbo-pulveriser. The normal forging temperature was 1,000° C.–1,200° C., but as an experiment the temperature of the furnace was raised 1,400° C. They remark that the low percentage of moisture makes the fuel suitable for pulverising, while the work of cleaning the flues of the furnace was reduced.

"According to Nielsen (*Gas Journal*, 1927, CLXXXVII, p. 254), tests on a large scale show that powdered semi-coke of the 'L. and N.' type has improved the usual steaming conditions, and Captain Brand, R.A.N. (Institution of Naval Architects, 1927, July 12th), describes tests carried out upon 'L. and N. fuel' from a Leicester coal by Messrs. Clarke, Chapman & Co., the efficiency quoted being 67·4 per cent. I am informed by Mr. Woodeson, of Messrs. Clarke, Chapman & Co., that so long as the temperature of the furnace is maintained above, say, 1,000° C., no difficulty whatever is experienced in the combustion of semi-coke as pulverised fuel, but below this temperature, should the volatile content be low, the flame may be extinguished. No difference has been experienced in the behaviour of the ash of semi-coke as compared with that of coal in the furnace. The wear and tear of the pulveriser was somewhat increased, but the product obtained tends to be of a more uniform grade, but at the same time slightly coarser than the coal. In view of the above, it is clear that the utilisation of low temperature coke in the pulverised form offers a promising field for industrial and scientific investigation."

A vast amount of research work has been carried out in this connection with the object of obtaining from raw coal the maximum possible quantities of fuel oil, and a number of these processes are now working on a small scale, considerable extensions being foreshadowed in one or two cases. The quantity of oil that can be obtained from a ton of coal by these means is small, averaging, perhaps, some 16–18 gallons of the crude oil; this product requires "topping," *i.e.*, partial distillation, if the lighter fractions (motor spirits, &c.) are to be made use of, the output of "topped" tar being about 14 to 15 gallons per ton of coal treated.

This residue after treatment can be used as a fuel oil, but contains appreciable quantities of pitch, the removal of which reduces the quantity of the final product to about 10 gallons per ton of coal. The oils obtainable from this source are not so suitable for use as fuels for highly forced boilers as are petroleum derivatives of shale oils, while doubt exists as to their miscibility with these latter and of their fluidity at low temperatures : all important points from the Naval aspect.

Each ton of coal so treated produces also about 12 cwt. of soft coke and 4,000 c. ft. of gas, the actual quantities of the various products and their quality depending upon the type of coal. In order, therefore, that the production of oil by these processes may be a commercial proposition, it is necessary to find a ready market for both the solid fuel and the gas at good prices : this practical difficulty is hampering the development of low temperature carbonisation.

With regard to the use of the solid fuel, although this can be ignited very readily and burns both comparatively smokelessly and with a fine ash, it is hardly to be expected that the public will buy this at a higher price per ton than house coal, and yet hitherto it has not been practicable to sell it at competitive prices. It has, however, been stated (although authoritative proof of this is lacking) that this fuel can safely be stored in the pulverised state, that it can be burned in this condition more economically than coal (in stoker fired boilers), and, further, that the power required for, and therefore the cost of, grinding is less than in the case of the latter. These statements have been used to make a *prima facie* case for the use of the low temperature coke as a pulverised fuel, but it must be added that the cubic measurement per ton of this fuel is greater than that of powdered coal, while its calorific value is lower; the disparity in this respect between pulverised coke and similarly treated coal will, of course, depend upon the sources from which the materials are drawn. It would appear reasonable to suppose that if gas and oil, both having appreciable heat values, are driven off from the coal then the resulting solid product should have a lesser heat value per pound than the raw coal itself. This view is to some extent borne out in practice, but obviously the comparative heat values of the raw coal and of its derivatives must depend upon the chemical composition of the various products and upon their relative densities.

It is pointed out that the ash is not driven off in the process of carbonisation, and this in itself tends to reduce the heat value of the coke : an ash content of 7 per cent. in the coal becomes concentrated to one of about 10 per cent. in the coke.

It is probable, therefore, that the "heat stowage" factor will militate against the use of pulverised coke, even if it is put upon the market in sufficient quantities and at an economic price: the possible saving grace lies in its alleged safety in its pulverised form, a point which may influence the ultimate value of the process. In conclusion it may be remarked that from the point of view of conserving fuel resources, it is more economical to burn the coal in its natural state than to expend heat to transform it into other substances, and this latter cannot be justified from this aspect unless the useful heat derived from the manufactured product equals the sum of that available in the raw coal and that employed in the conversion process.

The immediate need for oil may, in certain circumstances, outweigh this consideration, and in such an event low temperature distillation may prove of value. The extent to which it does so will depend, however, upon the character of the heavy oils produced by the process, the present indications being that such oils are not well suited for Naval fuels.

CONCLUSIONS.

It has been demonstrated that pulverised fuel can be economically burned in an ordinary marine boiler, and that at moderate rates of forcing the efficiency of combustion is better than that obtained in stoker fired boilers, and generally not inferior to good oil fired practice.

The overall economy as compared with oil fuel is prejudiced however, by the power requirements for handling and preparing the fuel: these are estimated at from 5 to 7 per cent. of the boiler output, as compared with 1 per cent. or less in oil fired boilers.

Development of the use of the fuel appears to be probable for mercantile work, at least in vessels of low power, while the way has been paved for the use of the fuel at high rates of burning and the principal factors involved are now fairly appreciated. Practical trials are required to demonstrate the best methods of handling, pulverising and transporting the fuel in a ship, and also to discover means for the safe storage of powdered coal. It appears at present that safety is best met by pulverising immediately before the fuel reaches the boilers. Investigations are now required regarding the types of fuel that can be burned, while attention must be directed to cutting down the size, weight and power requirements of the coal handling plant, especially as regards the pulverisers.

For Naval Services, the following points apply:—

(1) Low calorific value and low density as compared with oil fuel, thus necessitating increased bunker capacity for a given endurance.

(2) The size of combustion chamber required to burn this fuel is at present at least twice that provided in highly forced Naval boilers fitted to burn oil fuel.

It is probable that progress in this respect will be made, but the indications are that this can only be attained by the provision of additional apparatus and possibly at the cost of heavy wear and tear of the furnace linings. It appears certain that high grade coals of uniform quality and of a very fine degree of pulverisation will be essential for such services, while the use of preheated air will be unavoidable.

(3) The use of pulverised fuel entails special apparatus for its handling prior to burning and introduces complications as regards the transport of the fuel, whether raw or pulverised, from the bunkers to the boilers. In general these factors will involve additional weight and the provision of large pipes and trunks, possibly prejudicing to an undesirable extent the watertight sub-division of the vessel.

(4) Additions to the stokehold complements will be necessary if this fuel replaces oil, not only on account of possible requirements for handling the ashes and trimming the coal, but also because more frequent external cleaning of the boilers is to be expected.

Summing up, it is evident that, even if the various problems referred to are successfully solved, there still remains the handicap of a reduced endurance, while the weight and space required for the machinery will be unavoidably increased as compared with those in current oil fired designs. It is thus improbable that pulverised fuel can be adapted to Naval vessels under any conditions that can be visualised at present, save that of a stoppage of the supply of fuel oil. It is by no means impossible that altered circumstances may require this view to be revised, thus the development of the use of pulverised fuel cannot fail to be of real interest, although no immediate application for Naval purposes may exist.

Developments in the Mercantile Marine appear to be assured and may well prove a valuable national asset.