# THE ALTERNATIVE ENERGY SOURCE FOR SHIPS

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*ABSTRACT:* *The paper examines the pattern of energy utilisation in the Australian transport industry and the authors conclude that consumers able to do so should be encouraged to adopt an alternative to liquid fuel oils. The range of alternative energy sources available to sea transport operators include nuclear fuels, natural gas, coal, and derivatives of coal. Whilst a number of these alternatives could be employed without creating insuperable technical difficulties, it is suggested that economic and environmental influences really preclude all except coal from being seriously considered.*

*The paper discusses the major technical design considerations for coal-fired ships, including the detailed design of coal bunkers, handling systems, boilers, and land-side bunkering facilities. Careful attention is required to ensure that they are suited to the physical and chemical properties of the coals to be used.*

*More efficent steam generating plant and turbine machinery are constantly under development and the authors conclude with a short review of the future prospects in this area.*

20% extra capital of diesel for this one
Probably 15% once established

INTRODUCTION -

The rapid exhaustion of known world oil reserves has been widely acknowledged for some time now. Notwithstanding a decline in the rate of depletion over the past few years as a consequence of the combination of increased oil prices since 1973, the reduced level of world economic activity and a small degree of success in worldwide conservation efforts, at current levels of usage oil reserves will be close to exhaustion in about three decades. (See Table 1 below). The possibility that new discoveries, improved exploration and mining technology, further conservation measures and price increases may extend the availability of oil for a decade or two cannot be overlooked. The reduction or containment of consumption is highly desirable and any possible means of achieving this should be pursued. In the longer run however, natural oil will not be available and countries, in their efforts to improve and maintain living standards, will demand substitutes.

TABLE 1. WORLD ENERGY RESERVES AND UTILIZATION

(Billion Barrels of Oil Equivalent)

| Fuel Type | Proven Reserves | 1978 Production | Duration of reserves at 1978 production level |
|---|---|---|---|
| Oil | 640 | 22 | 29 (Years) |
| Gas | 450 | 9 | 50 |
| Coal | 3,050 | 12 | 254 |
| Uranium | | | |
| With LWR's | 250 | 4 | 62 |
| With Breeders | 17,000 | - | - |
| Shale Oil (Resources) | 3,330 | - | - |

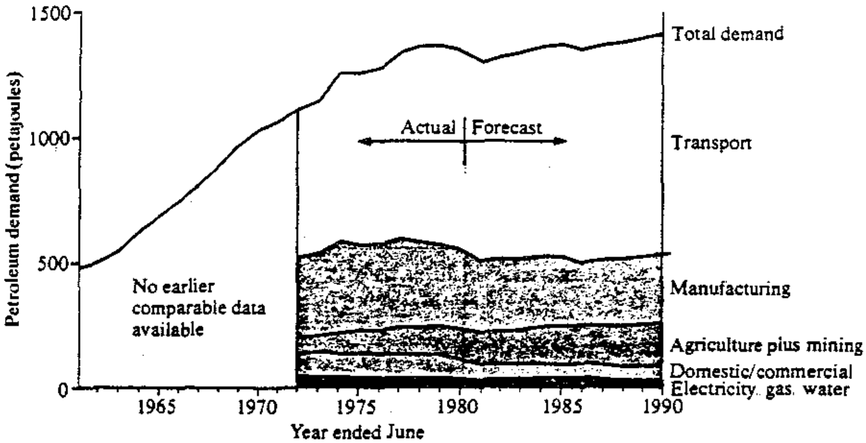
Source: I. Leibsen "Energy Resource Utilization in the Pacific Basin Countries".

Pacific Basin's Economic Council Meeting, 7 May 1980.

ENERGY UTILIZATION IN TRANSPORT INDUSTRY

Transport is a major user of oil, accounting for more than half of current and expected future (to 1990) consumption of oil in Australia.

**FIGURE 1: DEMAND FOR PETROLEUM FUELS BY END-USE SECTOR — AUSTRALIA**




N.B. Demand by end-use is represented by the vertical distance between adjacent lines. Total demand for each year is obtained from the aggregation of the individual component demands shown for that year

Source: Department of National Development & Energy "Energy Forecasts for the 1980's"

As far as the land transport/motoring segment is concerned, the industry is the least adaptable to the use of other available fuels. In the long term, use of LPG/LNG by transport vehicles is not a feasible alternative as gas is, like oil, a rapidly depletable resource with relatively modest reserves.

TABLE 2. AUSTRALIAN ENERGY RESERVES & UTILIZATION

| Fuel Type | Reserves | 1980 Production | Duration of Reserves at 1980 Production level |
|---|---|---|---|
| | | | (Years) |
| Crude Oil (Mill BBS) | 1,745 | 140 | 12.5 |
| Natural Gas (Mill BBS) | 5,325 | 60 | 87 |
| Coal (MTOE) | 56,452 | 54 (76/77) | 1,045 |

Source: Australian Institute of Petroleum Ltd.

P. J. Brain & G.P. Schuyers "Energy & The Australian Economy"

Synthetic liquid fuels, which can be derived from a wide variety of sources, may eventually offer alternatives to petrol. However, as the prices of these substitutes are likely to be substantially higher than current oil prices, the logical outcome would appear to be fundamental changes in long term patterns of motor vehicle usage rather than merely a switch to another form of liquid fuel.

In contrast to oil, coal resources are relatively plentiful (See Tables 1 and 2) and are expected to last for centuries, rather than decades. The properties of coal are established and proven. Technology exists for its efficient use and is being further developed. Substitution of oil by coal for power generation, cement manufacturing and other large "non mobile" uses has already, in many instances, been effected. In the transportation area certain shipping operations offer a prospect for the use of coal in a way which does not require a large outlay on research and development and which has a nominal effect on the environment.

However, despite the contention that coal offers the best practical alternative to liquid fuels in a number of sea-going trades, it will not provide a favourable economic solution for all. The dry bulk cargo trades are those in which the potential benefits will be most marked. The operational and design requirements of ships employed in the container and general cargo trades make it less likely that coal can be utilized economically except in certain isolated cases.

These general comments are particularly applicable to Australia. Australian reserves of oil are minute by world standards with less than half the world reserves' "life" at current consumption levels. On the other hand our situation in regard to recoverable coal is far more healthy and obviously any means of substituting coal for oil usage in the transport field merits encouragement.

## ENVIRONMENTAL POLLUTION

When considering the use of coal for ships bunkers, many people are influenced by their recollections of coal-fired ships of past generations. Coal is considered to be inseparable from images of stokeholds and dirty smokestacks, but these images themselves belong to the past. Modern coal-fired power stations are generally clean and a modern coal-fired ship can be designed to be wholly compatible with environmental standards acceptable to present-day communities.

Engineering practice and technology, much of it borrowed from current land-based practice, enables marine engineers and boiler designers to provide a working environment that compares very favourably with that of oil-fired ships and, at the same time, to ensure that atmospheric and environmental pollution is controlled within the limits imposed by statutory regulations. The purity of stack emissions in coal-fired merchant ships may readily be controlled by mechanical cyclone-type collectors and an efficient automatic combustion control system will regulate smoke densities at varying loads to give little more than a light haze at the funnel tops.

It may, in fact, be argued that a coal-fired ship can be designed to give less risk to its environment than its oil-fired counterpart, particularly if it is using an Australian coal as fuel. Australian coals are generally much lower in sulphur content than liquid bunker fuels and the injurious sulphur compounds formed during combustion and exhausted up the funnel will be proportionately less. The sulphur content of stack emissions is not yet a matter of concern in merchant ship machinery, but it has received attention for many years past in the more heavily industrialised regions of the world and it is by no means improbable that port authorities will introduce in the next few years further regulations limiting the extent of sulphurous emissions permitted within harbour limits.

The second feature of coal-fired ships that is beneficial to the marine environment is the absence of bunker fuel from the main and auxiliary machinery systems or, at least, a substantial reduction in the extent to which it is likely to be used. This means that there is a greatly reduced risk of contamination being caused by spillages when taking bunkers and, further, maloperation of an engine-room bilge system will have less damaging results. Coal dust is less harmful to marine life than liquid bunker fuel.

There remains the matter of ash disposal, which is frequently raised as a point of concern. In general, the ash produced from steaming coal is chemically inert and free of trace elements that are injurious to marine life. It may therefore be disposed of overside from a moving vessel without causing any disturbance to the environment in which it will settle, provided that it is not discharged over areas that support living coral. Coral is smothered by any fine particulate material that descends upon it and although the quantities of ash to be discharged from a single ship will be very small compared with the tonnages of silt and fine debris that move across the seabed from natural sources, the routine disposal of ash in such areas must be avoided.

There is no great difficulty in designing the shipboard installation to meet whatever requirements may apply to ash storage and disposal. Ash retention tanks may be built into the ship's structure, in which the ash may be stored while in port or while steaming in a restricted area. Unsightly "slicks" can be avoided by wetting the ash thoroughly prior to discharge and pumping it overboard below the waterline in the form of a slurry and, for use in emergency, the shipboard system can be provided with a branch line to allow the ash to be disposed of overside into a barge or shore receiving facility. It is well-known that coal ash has certain commercial uses and in years to come it may even become worth while to arrange for the routine collection ashore of the relatively small quantities generated in a shipboard system.

In terms of its overall impact upon the environment, a coal-fired ship should have some positive benefits when compared with more conventional oil-driven vessels. Despite the existence of stringent regulations, the pollution of the seas by oil is far from being eliminated and a ship powered by coal removes or greatly reduces that risk without introducing another of comparable severity.

## TECHNICAL DESIGN

### Design Objectives

The principal objectives to be satisfied in a coal-fired marine main propulsion installation may be summarised as follows:-

1. Maximum operational security during voyage conditions.
2. Maximum utilization of coal as the energy source
3. Minimum time out of service for repairs and maintenance
4. Optimum flexibility of operation
5. Suitability of unattended operation.

These objectives must be achieved at the most economical cost, assessed in terms of the estimated life-cycle of the ship, and in compliance with acceptable standards of environmental pollution.

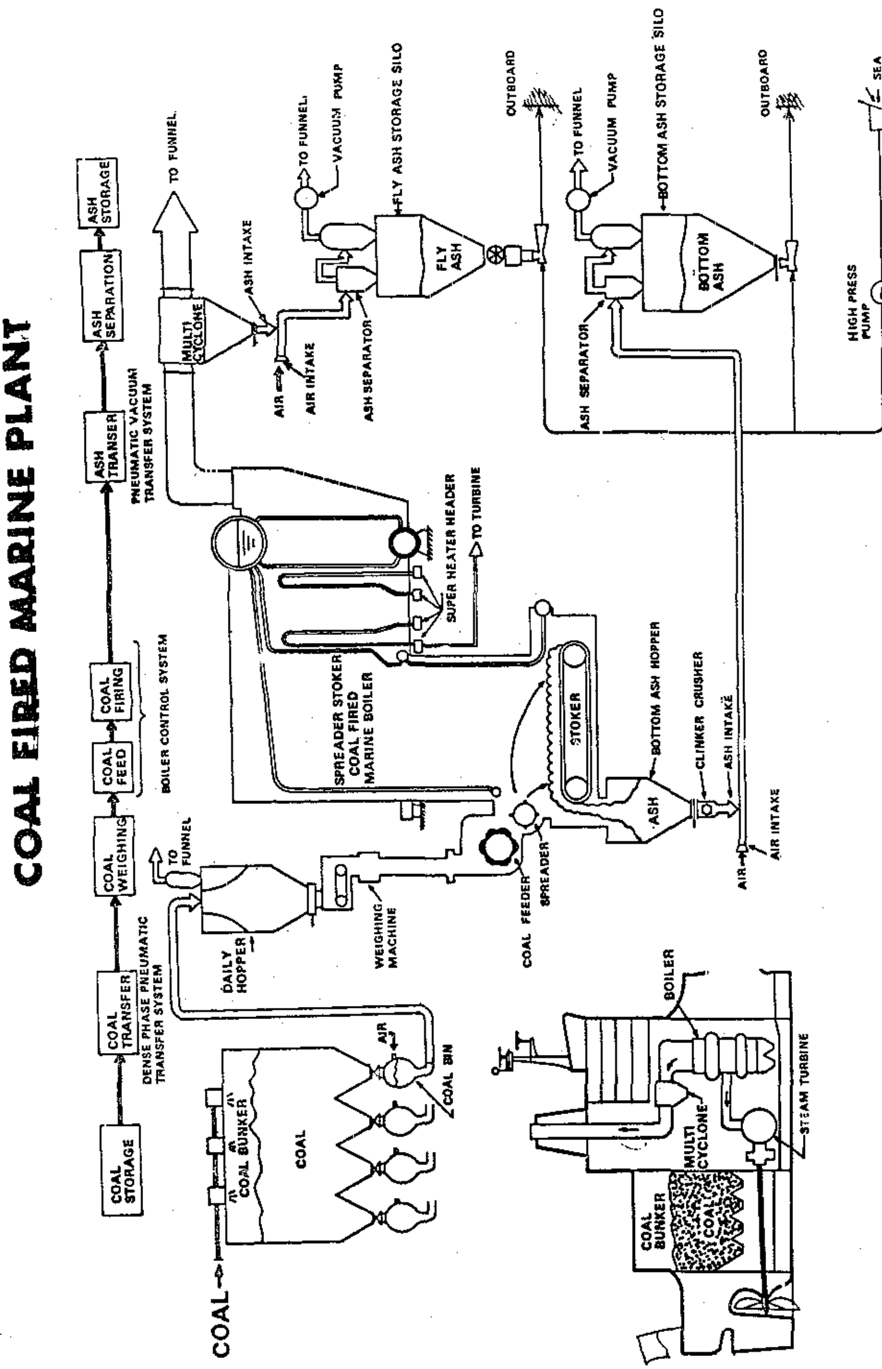



FIG. 2 DIAGRAM OF MACHINERY LAYOUT

## Operational Security

Security is of greater concern to a shipowner than to many operators of land-based plant because the loss of the source of propulsion power in a ship may well result in the loss of the total investment, let alone the lives of those that are tending it. This being the case, the system will be designed to eliminate, so far as practicable, the risk of the ship becoming totally immobilised.

It is not strictly necessary to install a twin boiler installation in order to provide adequate security. Modern marine boilers are very reliable in service and the choice of a single or twin boiler plant will be influenced more strongly by other considerations. In any case, the Classification Societies require that a single boiler installation must be supported by an approved "take-home" arrangement that is powered from a source wholly independent of the main boiler, such as an auxiliary diesel engine. Most shipowners today, however, favour a twin boiler arrangement, since this provides better operational flexibility as well as giving the extra security of a second boiler to maintain propulsive power in the event of some minor problem occurring in one of the pair.

## Maximum Utilization of Coal

Having decided for economic reasons to use coal as the fuel, it is desirable to exploit the economic benefits to the full by designing the plant to operate on coal under all normal conditions, at sea, in port, and for manoeuvring. Automatic combustion control can be employed over the full range of outputs required and a coal-fired plant can be designed to give dynamic responses during manoeuvring that compare very favourably with those of oil-fired boiler plant. Some small penalty may be incurred by the need to dump steam into the main condenser under certain intermittent low load conditions, but this will be less costly than employing liquid bunker fuel as an alternative for manoeuvring and harbour operation.

Similarly, electrical power should be supplied from turbo-generators powered from the main boiler rather than from auxiliary diesel sets, except for emergency power which must of necessity be supplied from a stand-by diesel generator.

There may, however, be other reasons that encourage a shipowner to adopt a dual fired arrangement for the main boilers, whereby they may be operated either on coal or on liquid bunker fuel. Such an arrangement is quite feasible and in the case of a ship intended for international trading the owner may choose to keep his options open for the future by accepting the higher initial cost of a dual fired plant for the sake of gaining greater flexibility. Pricing trends in bunker fuels are impossible to predict with any certainty in the long term and, during the 20-year life of a ship, there may well be occasions when it could be economically advantageous to take fuel oil as bunkers in order to employ the ship for a period in a particular trade attractive to the owner or charterer. Furthermore, for many years to come, the facilities available for bunkering fuel oils will remain far more widespread than those for coal and if the owner is in any way uncertain about the long term trading pattern for the ship in question then it will be prudent to adopt dual firing.

Such a decision must not be taken lightly, because the overall cost penalties may be severe, depending upon the type of ship and the range required when steaming on either coal or fuel oil. The extra cost of equipping the main boilers for dual firing will not usually be very high in proportion to the cost of the whole machinery installation, but the cost of providing additional fuel oil tanks within the hull structure and the corresponding loss of cargo revenue may require very careful evaluation before the final design is taken.

Minimum Down-Time

All plant operators seek to obtain the minimum loss of time due to maintaining and repairing the equipment under their control. In sea transport, this objective has gained increasing importance in recent years as improved methods of working cargo have led to much shorter periods spent in port, which are the only periods between bi-annual dry-dockings when it is possible to carry out maintenance work on the main propulsion machinery without causing voyage delays. The economic pressures of modern shipping have also greatly inflated the coast of any voyage delays that do occur, which may be regarded as the shipowners' equivalent of an interrupted production line in manufacturing industries.

The desire to achieve the minimum down-time in service will usually be a major factor in determining whether the shipowner selects a twin or a single boiler installation for a particular new building. Whilst marine boilers have a good record of general reliability, a number of minor problems occur both in the boilers and in their associated support systems that require them to be taken off line from time to time. In addition, there are routine surveys that have to be carried out, together with plānned maintenance procedures, many of which must be scheduled within the limited port turn-round times available.

In the twin-boiler installation, either boiler may be shut down without causing a great loss of speed to the ship. In the event of routine work being required at the next port of call, the boiler may be taken off line, say, 24 hours before arrival and thus be fully cooled down for work to commence immediately the ship has berthed. Shutting down after arrival, which is the only practical procedure in the case of a single boiler installation, may lead to a delay of 18 to 24 hours before repairs can be initiated, which, in many cases, is longer than the total time required for loading or discharging the cargo.

With regard to the remaining plant selected for the main propulsion and auxiliary machinery, shipowners are guided by the same principles as other operators. Particular types of equipment are evaluated in the light of past experience and system design is established on the basis of the most appropriate compromise between simplicity and fuel efficiency.

Unattended Operation

Many shipowners now require the machinery installations of modern newbuildings to be equipped for unattended operation for at least 16 hours out of 24. Continuous engine-room watches are no longer regarded as either desirable or necessary in order to achieve the best operating results.

The most obvious benefit derived from eliminating routine watchkeeping is that it enables the manning scale to be reduced, which gives a corresponding reduction in crew costs. There are however, other benefits that are equally important, for both practical and social reasons. Instrumentation and control systems have long since reached a standard of efficiency and reliability in which they are more dependable than human beings in sensing malfunctions or imminent malfunctions in complex machinery systems. They never - or very rarely indeed - suffer momentary distractions and they can check all points in the system continuously and for indefinite periods. In social terms, routine watchkeeping procedures comprise for the most part repetitive and unproductive activities that do not employ the skills of marine engineers to the best advantage. It is much better to arrange for instruments and monitoring equipment to attend to the relatively dull routines and thereby to release skilled personnel for more interesting and more productive work.

Provided that the shipowner is prepared to accept certain constraints, particularly in relation to the specification of the coal supplied for bunkers, the unattended operation of coal-fired marine boilers is entirely feasible. Further, it can be achieved at an initial cost that is no greater than that required to give a similar result in a diesel driven ship or an oil-fired turbine ship. Adopting coal as the fuel does not, therefore, imply that one has to revert to an operating procedure that has long since become outmoded in Australian-flag shipping.

## Coal-Fired Boilers

The selection of the most suitable firing arrangements for merchant ship boilers does not present the shipowner with a wide range of options. At the present stage of development of such units there is no practical alternative to a spreader stoker and travelling grate system of quite conventional design.

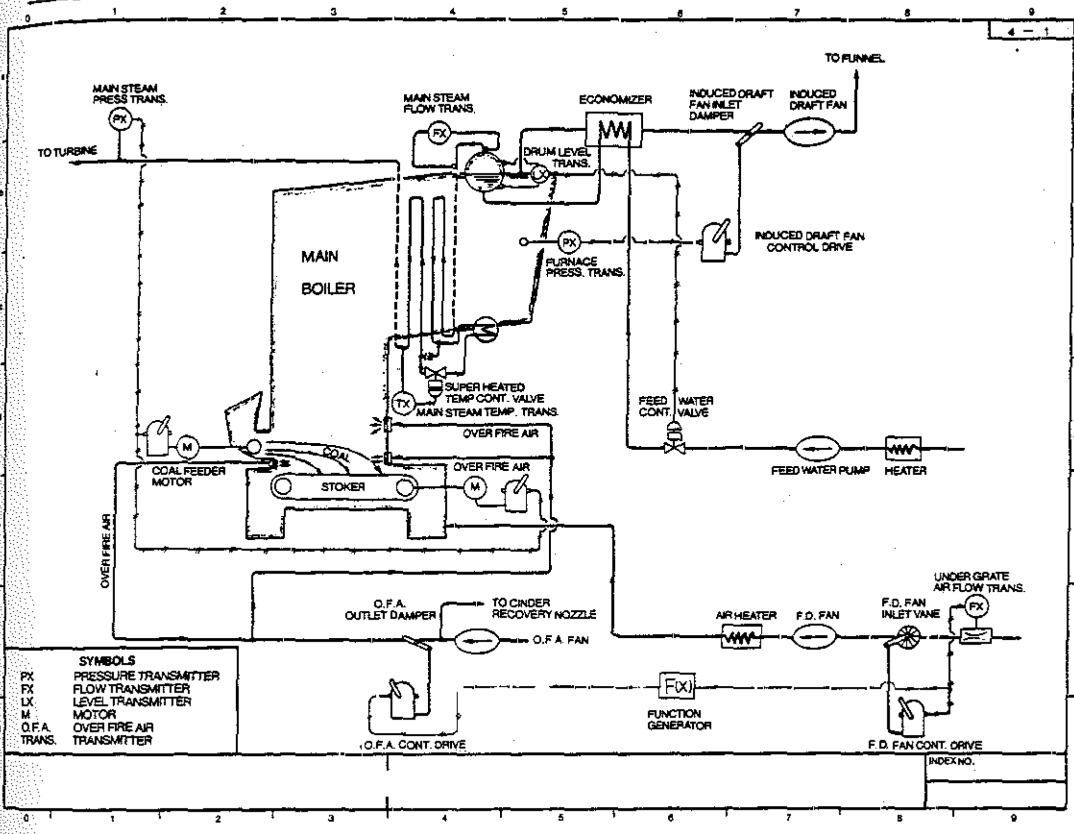
In ships for which a coal-fired alternative is likely to be competitive, the maximum evaporation rate will not usually exceed 70/80 tonnes per hour, even if a single boiler is selected in preference to a twin boiler installation. At evaporation rates of this order and below, a pulverised fuel system is not as economical as a stoker fired system, since the boiler itself is larger and more costly and the pulverising plant required to process the coal adds further to the capital cost. The higher combustion efficiency offered by pulverised fuel firing does not compensate for its higher initial cost and the increased costs of maintenance.

In addition, past experience has shown that pulverising mills do not generally perform very successfully when installed on a relatively flexible, moving platform, which is all that can be provided in a ship's engine room, whatever rigidity is built into the substructure and mountings. Further difficulties, attended by even higher initial costs, are presented by the need to provide dust extraction equipment capable of handling the substantially greater quantities of fly ash generated by pulverised fuel firing. Space is very much at a premium in a shipboard machinery installation and the installation of large precipitators or banks of bag filters cannot reasonably be considered.

Chain grate stokers were, in the past, used for marine installations, but they no longer offer acceptable dynamic responses during manoeuvring. Spreader stoker firing is more sensitive and more responsive to varying load demands, which is a consideration of paramount importance in marine practice.

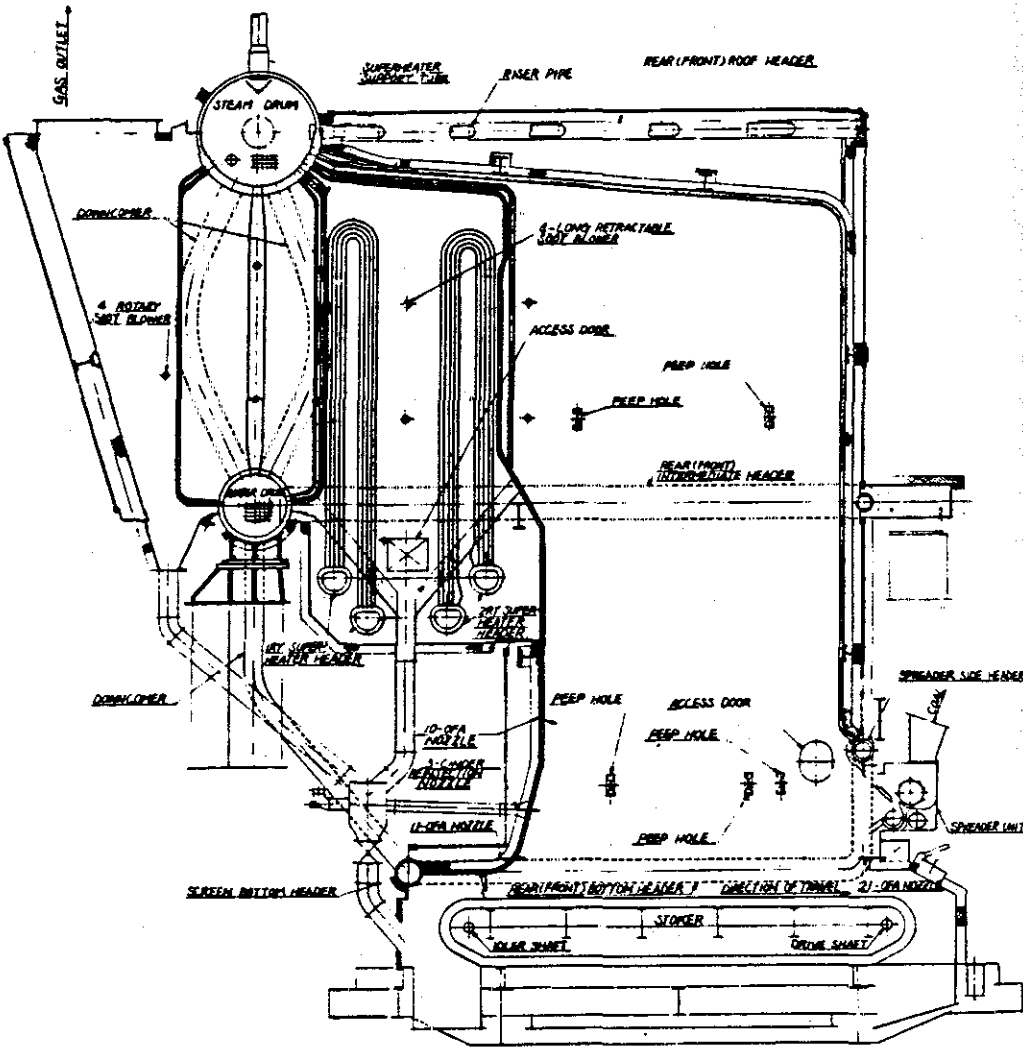
Whilst spreader stoker firing is undoubtedly the most economical choice today, there are other developments in hand that are likely to offer the shipowner a wider choice in the near future. In particular, fluidised bed combustors will, within the next few years, be developed to a stage where it is probable that they will offer a viable alternative for marine steam generating plant. In the Authors' view, however, that stage has not yet been reached.

Fig. 3. FLOW DIAGRAM FOR COAL FIRED BOILER




Despite the preferred firing arrangements being recognisably similar to those adopted in some coal-fired ships of an earlier generation, the combustion controls can now exploit the best of modern technology to maintain efficient firing over a wide range of outputs. A standard stoker firing system, however, will not provide a turn-down ratio greater than 4:1 on automatic control, although further manual adjustments will enable good combustion to be maintained down to approximately 15% of maximum output.

Fig. 4 ARRANGEMENT OF BOILER



This turn-down ratio is quite adequate for most operating needs, particularly when associated with an automatic steam dumping facility that provides for excess steam to be dumped to the main condenser in order to accommodate the more extreme conditions of rapidly decreasing load demands during manoeuvring. A substantially greater turn-down ratio may be obtained by designing the boiler with a divided grate and segregated under-grate air compartments that permit one section of the firing grate to be operated quite independently. In this arrangement, during manoeuvring or when operating at extremely low outputs, firing is maintained only on that section of the grate that is necessary to meet the steam demand. Since the combustion control system still provides for a turn-down ratio of 4:1, utilising only one half or one third of the grate area gives an overall turn-down of 8:1 or 12:1. There are, of course, certain complications in the grate design in order to achieve the improved turn-down, but these do not present any great difficulties to the boiler designers and a decision whether or not to adopt such refinements is determined largely by the overall economic considerations that apply to a specific operating need.

The automatic combustion control system for a stoker-fired boiler is similar in its principles of operation to that for any oil-fired boiler, the basic requirement being to maintain the optimum fuel/air ratio over the specified range of evaporation. Steam pressure and steam flow will be monitored to provide the control signals for fuel supply, which is regulated by varying the speed of the feeders that supply the coal to the rotary spreaders. Grate speed should also be regulated in order to assist in maintaining an even firing bed under the varying conditions of coal feed. Primary air flow may be controlled by means of the forced draught from suction damper settings, the control signals being taken from the same source as the fuel supply controls.

Control of the induced draught fan output is exercised by sensing the pressure in the balanced draught furnace and adjusting the inlet damper vanes accordingly, whilst the secondary overfire air control is linked on a linear basis with that of the primary air.

Steam conditions may be selected to suit the shipowner's specified requirements and the adoption of coal-fired boilers imposes no restrictions in relation to current marine practice. As is well known, the steam conditions in modern merchant ships are well below those that prevail in land-based power stations and typical values in marine practice are a pressure of 6,000 kPa at the superheater outlet and a temperature of 515°c.

FIG. 5 CONTINUOUS DISCHARGE SPREADER STOKER

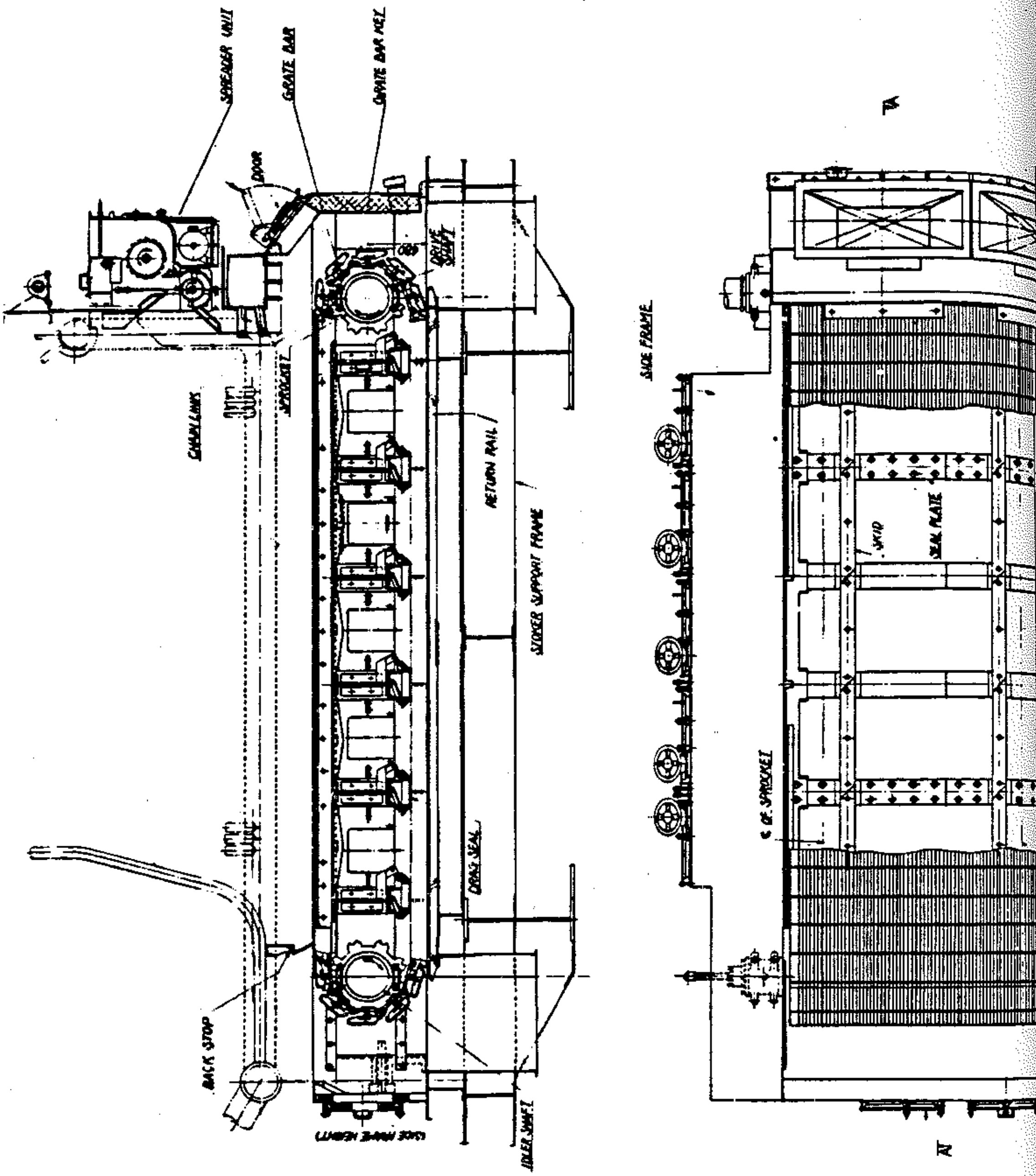
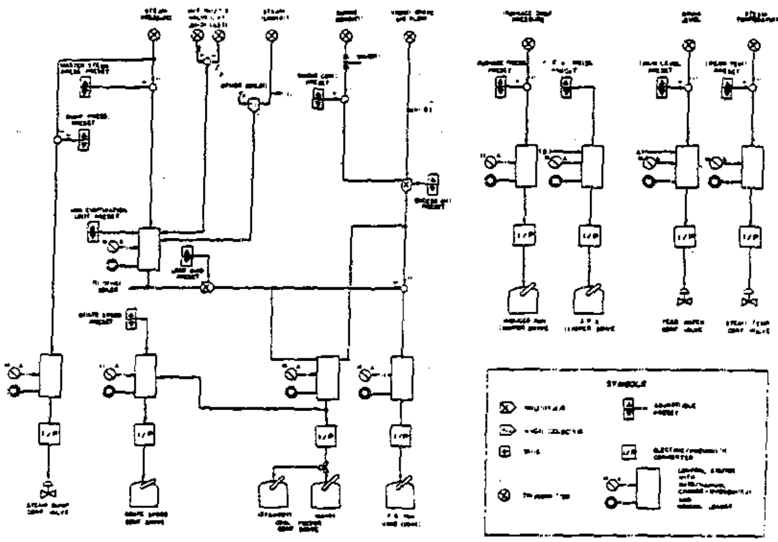


Fig. 6 COAL MACCS BLOCK DIAGRAM



## Coal and Ash Handling Systems

During the earlier years of this century, one of the factors that encouraged the change from coal to oil fuel was the convenience with which the liquid fuel could be stored and handled on board ships. Pumping the fuel through pipes was easier, cleaner, and less labour intensive than having to shovel coal. A number of mechanical conveying systems were developed later for transferring coal from the main bunkers to the service hoppers adjacent to the boilers, but by this time cheap fuel oil was readily available throughout the world and there were no economic pressures to induce shipowners to consider coal as an alternative, except in one or two strictly localised trades.

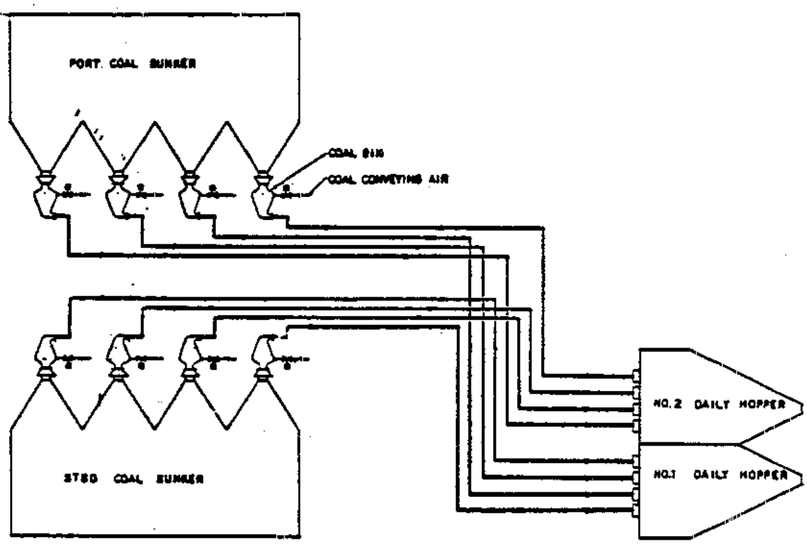
Probably the most significant technical developments of direct interest to the designers of coal-fired ships have been those related to the use of pneumatic systems for carrying coal. The coal handling practices common to previous generations of coal burning ships could not satisfy present-day standards of safety, working environments, or pollution control and a more efficient method of handling coal on board is essential to the success of any concept designed for the 1980's.

Pneumatic handling enables the solid fuel to be transferred through a piping system that is essentially similar to that used for a liquid fuel. In operational terms, this is more convenient, more flexible, and more familiar to the operating personnel than any alternative. A pneumatic handling method also occupies less space than a mechanical conveying system, eliminates the accumulations of coal dust within conveyor casings, and avoids the risk of tramp iron being introduced into the hoppers due to random breakages of metal conveyor components.

It also carries the important advantage of reducing the overall maintenance load associated with the conveying system. The principal disadvantage is that the air compressors will consume more power than the drive motors of a mechanical system, but this is of relatively little significance when related to the total electrical power that must be installed to maintain all the other ship's services. A further disadvantage is that a pneumatic system is more sensitive to coal sizing and to variations in the physical characteristics of the coal than is a mechanical system, but the operating benefits comfortably outweigh these penalties when evaluating such a system for shipboard use.

Of the two types of pneumatic system in common use ashore, lean phase and dense phase, it is probable that the dense phase design is better suited to shipboard use for coal conveying purposes. The required transfer air volumes are less, which reduces the size of the compressors and the cost and complexity of the venting and filtering arrangements at the points of discharge; the lower pipeline velocities reduce the rate of abrasion of the system pipework and also reduce the risk of static discharges occurring at the outlets; and the system characteristics, in comparison with the lean phase principle, will tend to cause less degradation of the coal during the transfer process.

Fig. 7 COAL CONVEYING SYSTEM DIAGRAM




A dense phase conveying system is well suited to automatic control. The process of filling the daily service hoppers from the main bunkers may be programmed to give sequential operation of the outlet gates from each hopper section of the main bunkers, thereby maintaining the proper trim in the bunkers to reduce the incidence of "rat-holing". In principle, therefore, it is a system that conforms very well with the overall concept of a modern shipboard machinery installation designed to minimise the labour-intensive aspects of its operation.

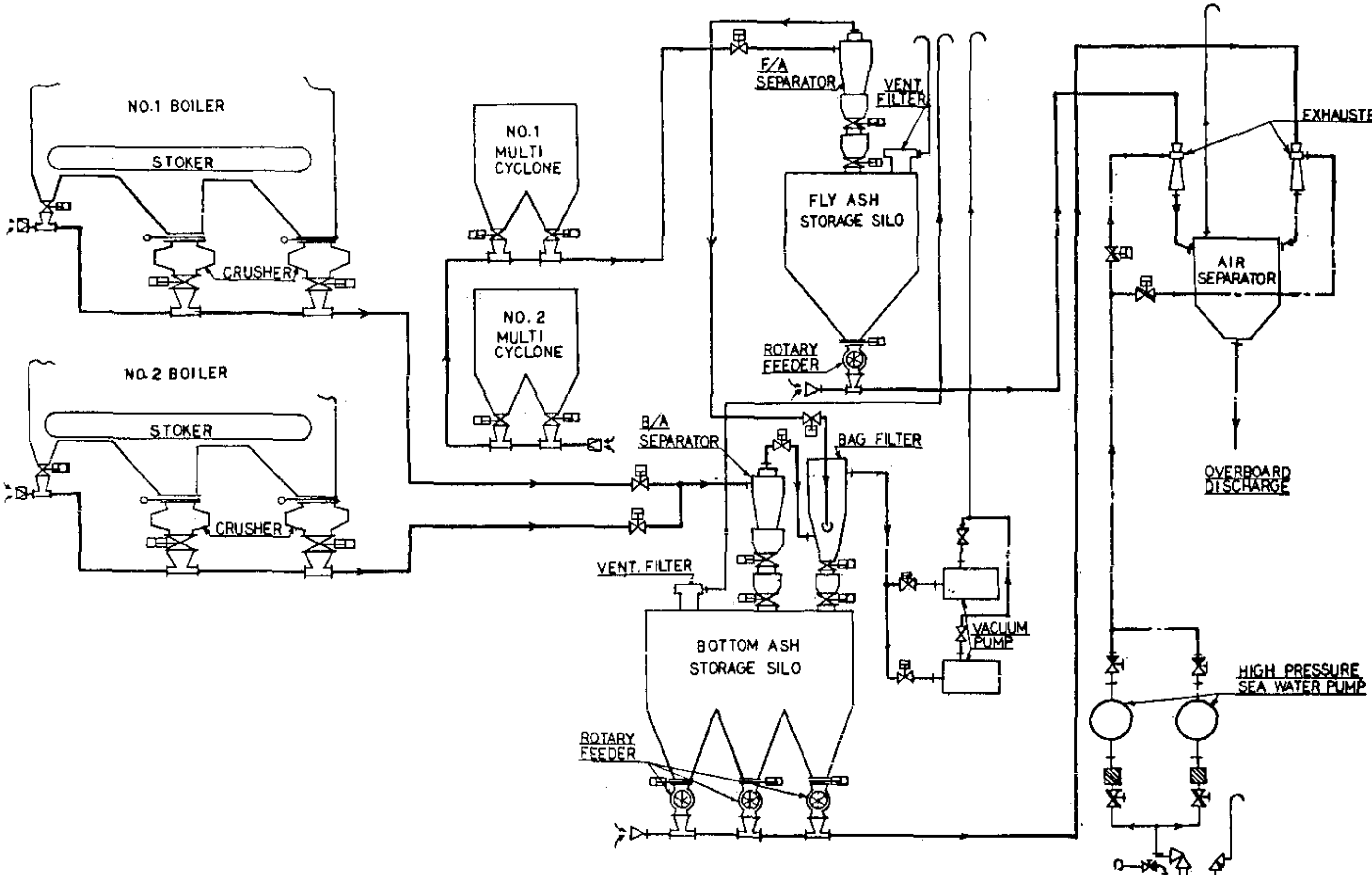



Fig. 8 ASH HANDLING SYSTEM FLOW DIAGRAM

FIG 8 ASH HANDLING SYSTEM FLOW DIAGRAM

Proving trials with a particular coal or range of coals will undoubtedly indicate that the optimum performance of a dense phase conveying system is obtained within well-defined limits of the physical characteristics of the material to be transferred. The top size must be controlled to suit the nominal bore of the piping in the system and the surface moisture content will also influence the ease and efficiency of the process. Since the successful operation of any modern, highly automated power generating system demands that careful control is exercised over the quality of its fuel, the particular needs of dense phase conveying systems do not, in this regard, impose any unacceptable restrictions upon the designers.

Ash handling in a marine installation will normally be carried out by a vacuum pneumatic or pressure pneumatic system of a type quite familiar in land-based practice. Most coal-fired ships will require on-board storage facilities to provide for any unscheduled delays in port or at anchor within harbour limits and additional restrictions regarding the disposal of ash overboard may apply on particular trade routes. This being the case, hydraulic or slurried transfer systems necessitate the fitting of much larger storage tanks to accommodate the larger volume of the ash/water mix and such systems, if used at sea, will normally be confined to the final stage of the ash handling process in which it is positively beneficial to discharge the ash overboard from the storage tanks into the sea in the form of a slurry.

In the case of stoker fired boilers, the ash handling system comprises two main sections, one for transferring the fly ash from the multi-cyclone dust collectors and one for transferring the bottom ash from the boiler grates. These will be supported by a smaller ancillary system for handling the relatively small quantities of fine ash that sift through the grade. When designing the total system, estimates are required of the total quantities of fly ash and bottom ash likely to be generated from the particular coal being burned in the boilers and the capacity of each section specified accordingly. The arrangement of the storage tanks may provide for common storage of both fly ash and bottom ash or for the separate storage of each.

The ash handling system may also be designed for fully automatic operation, at least up to the point of storage in the tanks. It is preferable that the overboard discharge function should be initiated manually at all times in order to eliminate the risk of a control malfunction leading to accidental discharge in a prohibited area, but even this process may be arranged to shut down automatically when the ash storage tanks are fully discharged. In a modern ash handling system there is therefore very little human intervention required in order to achieve successful operation, but, as with other systems associated with modern coal fired boiler plant, trouble-free operation under automatic control will depend largely upon a reasonable degree of consistency being maintained in the characteristics of the fuel supplied as bunkers.

Coal Bunker Design

Ships' bunkers should be designed to achieve precisely the same results as coal bunkers installed elsewhere - they should preferably be self-trimming and designed to provide an even and uninterrupted mass flow of the coal to the hopper outlets with the minimum segregation. Different coals behave in different ways and the characteristics of the coal or range of coals to be used must be studied before the final design of the bunkers is completed. The minimum acceptable slope angles in the hopper sections and the adoption, if required, of low-friction lining material for particular surfaces will depend upon the physical behaviour of the coal at varying fines contents and moisture levels. In the absence of adequate information being available from other users of the coal in question, the shipbuilder, in association with the owner, will be well advised to study this behaviour in depth, preferably utilising large-scale mock up sections of the proposed bunker arrangements to determine the most satisfactory configuration.

A modern ship will require somewhat more accurate means of determining how much coal remains in the bunkers than were considered necessary in earlier times. Either ultra-sonic level detectors or access points for taking sullage soundings can be used, but the number and location of the sounding points will require very careful selection in order to achieve acceptable standards of accuracy from the readings taken by the ship's staff. Equally important in this respect is the arrangement of the coal discharge points into the bunkers which must aim at achieving an evenly distributed filling in order to minimise the segregation of lumps and fines. Whilst segregation is the prime consideration in determining the arrangement of bunker inlet and outlet points, it is very difficult indeed to establish accurate estimates of the coal remaining unless a reasonably even trim can be maintained in the bunkers throughout all levels of their capacity. If the distribution of bunker inlet and outlet points is determined correctly in conjunction with the location of the various sounding points, then the contents of the bunkers may be estimated with fair assurance within 10% accuracy, which is adequate for most purposes.

Properties of Coal as Ship's Fuel

Many land-based operators have remained familiar with coal but in the shipping industry we have to learn again how to handle it and burn it to the best advantage. To a generation of engineers brought up almost exclusively in the operation of oil-fired steam turbines and diesel engines, this re-education calls for careful study.

In general, coal varies far more widely in its physical properties and thus in its behaviour than liquid bunker fuels. For marine use, therefore, a compromise has to be reached between the demands of the specification of the coal considered to be acceptable and the limits of flexibility of the shipboard equipment designed to accommodate it. The tighter the specification, the higher will be the cost of the coal and the first step in the learning process is to understand that the most practical compromise will probably result in the fuel taken as bunkers being less consistent in quality than has been commonplace during the era of oil-fired machinery. In particular, ash and moisture contents will vary quite substantially even in different batches of coal taken from the same mine, which will influence the gross consumption and the handling characteristics to an extent that will be wholly outside the past experience of marine engineers from oil-fired ships.

To a Chief Engineer who has been used to measuring his daily oil consumption consistently within a tolerance of, say, $\pm$ 2%, determining his gross coal consumption will frequently require him to accept less precise standards of accuracy. A ship is subject to pitching and rolling movements in a seaway, which render coal flow measuring devices ineffective if the angle of movement in either plane exceeds about $5^{o}$. In fair weather, therefore, it is possible to measure the gross consumption within a tolerance of $\pm$ 2.5% by means of a coal scale, but under heavy weather conditions one must resort to volumetric methods of measurement that may achieve an accuracy no better than $\pm$ 10% when interpreted from a background of sound practical experience with the installation in question.

Having studied a number of alternatives for measuring gross consumption on an hourly or daily basis, it is the Authors' view that a gravimetric coal scale provides the most effective means of providing consumption data in marine boiler plant, since it at least offers tolerable accuracy during the periods when the ship is in port or steaming in fair weather.

When selecting a coal for marine use it is necessary to look beyond the simple matter of heat content, despite the undoubted importance of this property. A low heat content will usually be associated with a correspondingly low price per tonne, but the principle disadvantage of coals of this type for use as ship's bunkers is the correspondingly greater volume that has to be allocated for bunker space to achieve a given operating range. The calorific value of a good steaming coal is in the order of 6,600 kCal/kg and if one is required to bunker coal having a calorific value of, say, 5,500 kCal/kg, as may well be the case, about 20% extra space is needed for the bunkers. None the less, coals with low calorific values may still burn cleanly in the boiler furnaces and the fouling and slagging characteristics of the coal to be used are just as important as the heat content in achieving trouble-free operation of the plant. In this respect it is most desirable, if not essential, that the boilers are designed with maximum gas temperatures in the furnace that are comfortably below the ash deformation and ash fusion temperatures of the coal.

In practical terms, coal is a wholly feasible alternative to liquid fuels for modern ships provided that the shipowner and the shipbuilders accept that modern boilers and their support systems demand closer attention being given to fuel quality than was commonplace in the coal-fired ships of earlier days. In order to achieve successful operation in a working environment appropriate to the 1980's, the coal should preferably be bunkered from one source or, if this is not practicable, the coals from different sources should be matched as closely as possible, with particular reference to the sizing and the ash fusion temperatures. Given this attention to achieving a reasonable consistency in the fuel quality, the coal-fired installation may be operated as conveniently as any oil-fired alternative and at a lower overall cost.

## BUNKERING FACILITIES

The extent to which coal-fired ships are employed during the next few years will be influenced very largely by the availability of bunker supplies, even in the trades for which they can be shown to be economically advantageous.

The coal carrying trades would seem to provide the most attractive outlets for coal burners, since the ships' bunkers can, in most cases, be filled at the same berth at which the cargo is loaded. Further, there are a number of export outlets for Australian-produced steaming coal in which it would be quite feasible in terms of the economic factors to take bunkers at the loading port for a complete round voyage and to refill them only upon returning to Australia. Even in these trades, however, some extra investment will be required to ensure that the coal taken aboard as bunkers is sized to suit the ship's plant and that its other physical characteristics are controlled within the limits required to give trouble-free steaming. Shipowners will be fortunate indeed if the characteristics required of the coal to be burned in the ship's boilers co-incide with those specified by the export customer.

In practice, the most that would usually be required at a coal loading port would be a small screening and crushing facility through which would be passed the coal intended for use as bunkers. In some instances, it might also be considered preferable to install an independent conveyor for bunkering purposes only, in order that the bunkering process could be carried out at the same time as the loading of the cargo, but the need for investment in such equipment would be determined by the nett financial gains derived from the quicker turn-round times and shorter periods of berth occupancy of each ship. In any event, it is more than likely that the annual throughput of coal to be handled as ships' bunkers would permit the capital cost of both crushing and conveying plant to be amortized over an acceptably brief period without having to inflate the cost per tonne of the bunker coal to a level that jeopardised the economic advantages of coal burning ships being served.

The same reasoning may be applied to the establishment of bunkering facilities at a number of ports on the eastern seaboard of Australia concerned with cargoes other than coal. It is impossible to generalise, because each case requires separate study in the light of the various economic factors that apply to the particular commercial requirement under review. However, from their knowledge of one trade in which coal-fired ships are operated by their Company, the Authors are of the opinion that quite substantial investment in shore bunkering facilities can be supported without the operator of coal-fired bulk carriers losing his competitive advantage over oil-fired ships in the same trade. The cost of establishing such facilities should not therefore be an insuperable barrier provided that their continued utilisation can be assured for a period that enables the investor to gain an acceptable return on his funds.

The technical aspects of bunkering will not present any great difficulties. There are a number of conveying systems that enable bulk materials to be handled cleanly and conveniently at discharge rates that are quite adequate for bunkering purposes. In certain cases, it may be possible to employ a pneumatic system, although the relatively low capacities presently offered by such systems are unlikely to make them competitive at discharge rates above 200 tonnes per hour, which may not be sufficient to meet the required turn-round time at the bunkering port.

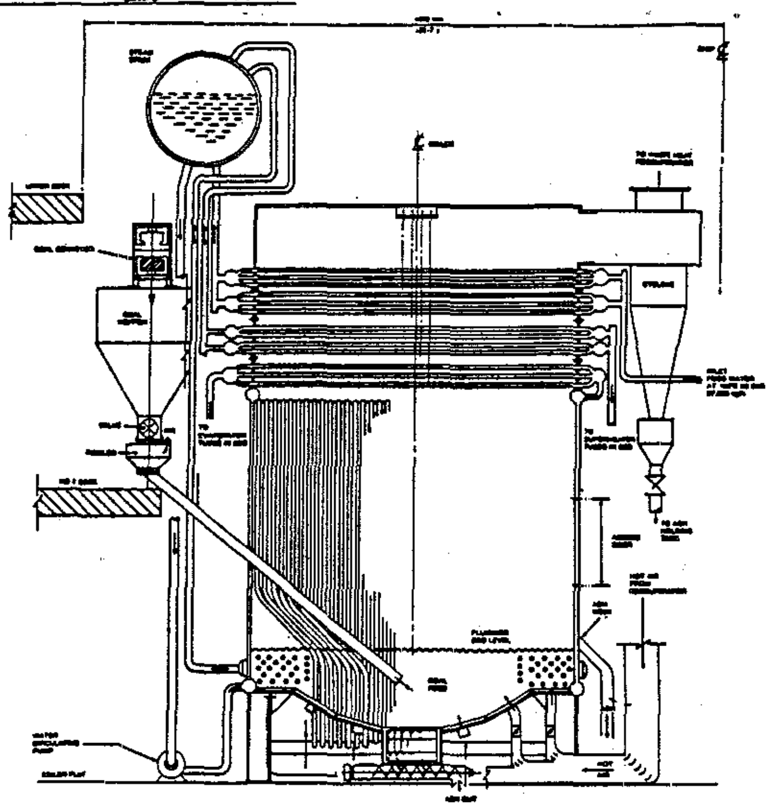
## FUTURE DEVELOPMENTS

In the Authors' opinion, a return to coal-fired ships should be regarded as an intermediate step, beneficial to certain trades, between the era of oil firing and the development of entirely new energy sources that will undoubtedly come to pass during the next 50 years or so. Even within this time scale, diesel engines powered by liquid bunker fuels will remain predominant, but there are certain technical developments now well in hand that are likely to improve the competitiveness of turbine machinery.

Steam cycle efficiencies in marine propulsion plant are consistently being improved by turbine manufacturers and there is undoubtedly much room for further improvement by increasing the commonly accepted steam conditions to levels that match more closely those that prevail in land based practice. Reliability, however, must remain of paramount importance and the complexity of a marine propulsion system must never lose sight of the occasional need to carry out repairs with limited resources of both materials and manpower.

The more significant developments will be made in improvements to steam generating plant, both in achieving higher thermal efficiencies and in their ability to accept fuels of indifferent quality. As was noted earlier in this paper, the only practical choice at present for firing a coal-fired marine boiler is the spreader stoker system. One reason why pulverised fuel firing, with its higher thermal efficiency, is uncompetitive in relatively low powered marine installations is that there has not hitherto been any incentive for boiler manufactuerers to develop suitable units. Their skills have been properly applied to the land based market in public utilities and large industrial plant. Given the commercial incentive, however, there are surely no insuperable barriers to the development of smaller P.F. fired boilers, together with their essential support systems, that could be applied economically to marine applications.

Fig. 9 FLUIDISED BED COMBUSTOR



Of even greater potential value to the shipping industry are the current developments in the application of fluidised bed combustors to steam generation. Steam generators of this type offer the distinct advantages of higher thermal efficiency combined with reduced size for a given output. On present evidence, they also offer much greater flexibility in their ability to accept different fuels of widely varying quality and consistency. Of these potential benefits, it is the relative compactness of fluidised bed combustors that has the greatest appeal for marine applications, since it appears very likely that a combustor designed to operate on coal will be no larger in overall dimensions than an oil fired marine boiler of equal output. There are a number of technical problems yet to be resolved before fluidised bed combustors may be selected with any degree of confidence for marine steam generating services. In particular, the fuel supply arrangements require further study and the most effective means of achieving the required turn-down ratios to suit marine operating requirements have yet to be determined on a commercially viable basis.

There is little doubt, however, that these problems will be resolved and that fluidised bed combustors will, within the next 3/5 years, be developed to a stage at which they will represent an alternative to conventional coal-fired boilers that merits very serious consideration.

As an extension to the concept of selecting fluidised bed combustors as pure steam generators, shipowners should not ignore their potential application to combined cycle systems, in which steam generated in the combustor is used to power a conventional steam turbine and additional output is gained from utilising the energy in the exhaust gases from the combustor to power a gas turbine. This combination, while comprising an overall installation of some complexity, offers significant gains in thermal efficiency and in fuel flexibility that are of considerable interest for the future.

The precise pattern and pace of future developments in any technology are impossible to predict with any degree of certainty, because they are determined by commercial pressures and economic influences that are in themselves unpredictable in the medium to long term. It may, however, be stated with fair assurance that the present concepts of coal-fired ships, based as they are upon combustion systems that in many respects are recognisably similar to those of a past generation, will be revised extensively within the next few years to exploit the benefits of the new developments that are currently being pursued.