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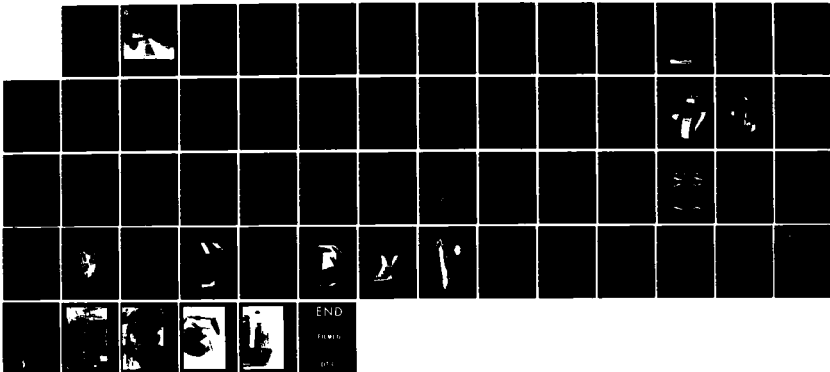
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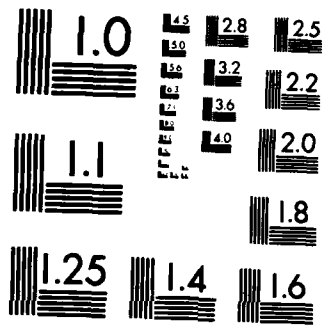
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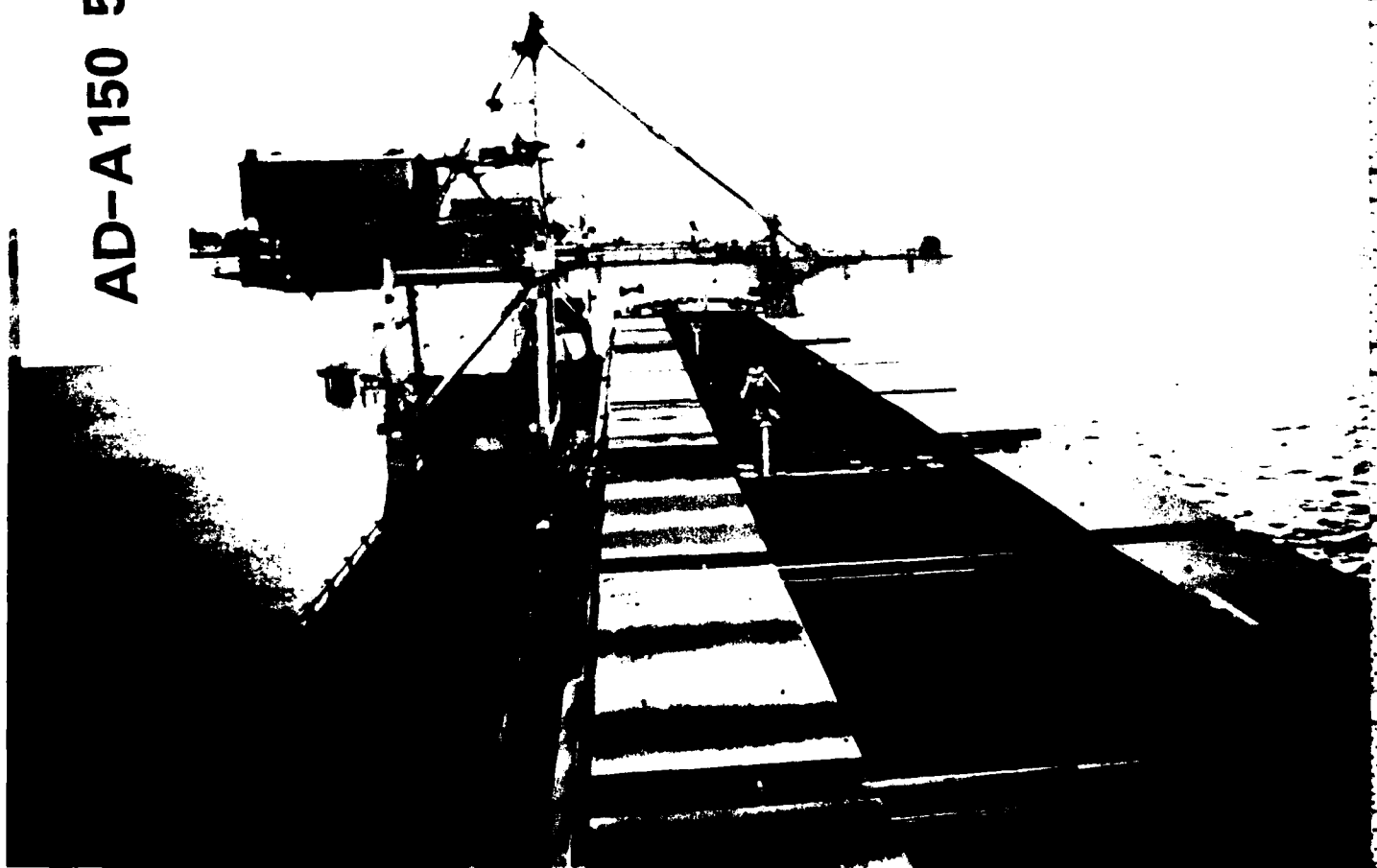


U.S. Department
of Transportation

Maritime
Administration

AN INITIAL ASSESSMENT OF COAL-FIRED SHIP OPERATIONS

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**TECHNICAL REPORT
FOR AN
INITIAL ASSESSMENT OF
COAL-FIRED SHIP OPERATIONS**

SUBMITTED TO
U.S. DEPARTMENT OF TRANSPORTATION
MARITIME ADMINISTRATION
OFFICE OF ADVANCED SHIP DEVELOPMENT
WASHINGTON, D.C. 20590

SUBMITTED BY
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EXECUTIVE SUMMARY

The current economic and political problems associated with petroleum derived fuels, along with their projected future availability and quality, have led to considerations of alternative energy sources both ashore and afloat. One alternative fuel that has steadily increased in use in shore-based plants is coal in direct and slurry forms.

The purpose of this report is to summarize the recent operational experience and issues surrounding the design, construction and operation of the new generation of coal-fired ships. The experience summarized in this report is based upon direct discussions with shipowners, operators and shipyards as well as data published in the open literature. The assessment also included regulatory agencies and appropriate marine industry manufacturers involved with coal-fired ships.

The ship operators and owners of seven of these new vessels have overwhelmingly given their endorsement of coal-fired propulsion systems. They admit having "startup" problems in the areas of fuel quality, coal transfer, ash handling and, in one case, stack design problems, which were all related to the propulsion system. However, the viability of these ships has been proven in-service. They report no major loss of time or revenue due to the propulsion systems. There has been extra crew workload and numerous backfits required to correct problems. In general shipyards and equipment manufacturers have honored guarantee commitments and re-worked their hardware to keep the ships operating smoothly.

Economic viability is the reason for the solid support of coal-fired propulsion. It has proven to be a viable economic alternative to oil-fired steam and diesel plants. All owners/operators surveyed claim substantial cost savings in the price of coal "as delivered" to the customer when compared to the delivered price of coal using either diesel propelled or oil-fired steam turbine propelled vessels. In many instances, this is directly related to the very low price for bunker coal. While many variables entered into the cost comparisons for each owner, they do represent the order of magnitude of savings realized. The economic incentive to solve the operating and design problems is unquestioned and the owners would consider coal-fired propulsion the leading candidate for new construction of bulk vessels in similar trades.

INTRODUCTION

This report is intended to outline and define the questions and issues related to recent operating experience of coal-fired propulsion systems in merchant vessels. The subject of coal-fired steam plant propulsion is a topic of much current interest. This study was conducted for the United States Maritime Administration.

Prior to construction of this new generation of ships, the only coal-fired propulsion systems in operation in the United States were on the Great Lakes [1]. These ships were generally built during the 1920's and 1930's and employ manual dump type grate systems. The stokers are difficult to operate and generally do not meet present day air pollution requirements. Most of the new generation of coal-fired vessels have completely automated propulsion machinery with alternative control from the Engine Control Room or Bridge and have been classed to Lloyds Register U.M.S. (Unmanned Machinery Space) requirements.

U.S. Coal Export Growth

A series of authoritative studies have predicted increases in the volume of world coal trade during the coming decades. A large share of this trade will be exported from the United States.

The OPEC oil embargo in the seventies and the steadily increasing value of the U.S. dollar resulted in a long term shift from oil firing back to coal and coal-derived fuels for land based utility boilers. This increased utilization of coal will increase both supply and demand on a worldwide bases during the coming decades. Worldwide coal reserves amount to about six times the proven reserves of crude oil [2].

World coal recoverable reserves can be summarized as follows:

	Billion Tons	Percent of Total
United States	178	27.9
China	110	17.3
United Kingdom	99	15.5
Germany	45	7.1
India	34	5.4
Australia	27	4.3
South Africa	27	4.2
Poland	22	3.4
Canada	9	1.5

An aggressive export policy by Australia, South Africa and the U.S. East Coast has resulted in increased trading on the spot market for steam coal. It has been predicted that by the year 2000 oil consumption will decrease in the developed nations, and non-oil energy consumption will increase more than 100% over 1979 levels. The changeover of oil fired land-based power generating facilities to alternate energy resources is a long term process. Coal in direct and slurry forms is emerging as a favored fuel source for several reasons:

- o Coal reserves worldwide are massive.
- o Coal is available on a long term contract basis from economically and politically stable countries.
- o Economics of coal-fired plants are considerably better than other alternatives.
- o Technology for coal-firing is well established and requires minimum development.

The Interagency Coal Export (ICE) Task Force was formed during the spring of 1980 [2]. In a report issued January 20, 1981, the ICE projected that by the year 2000 annual world trade of steam coal would reach 500 million metric tons (mmt). The U.S. share was estimated to be up to 200 mmt or 40 percent of the total (Refer to Figure 2-1). The projections assume that U.S. suppliers would be able to keep their prices in the competitive range. However, these projections have not yet been realized.

The surge in metallurgical and steam coal exports experienced in the United States beginning in 1980, was interpreted by many as the beginning of this upward trend in world steam coal demand. The corresponding labor problems in Australia and Poland, together with increased shipments from other major coal-exporting countries, resulted in port congestion in 1980 and 1981.

On a delivered cost basis, the price of U.S. Coal was found to be non-competitive with that of other suppliers. This made the United States a marginal supplier to Western European and Far Eastern markets. Australia is the least-cost supplier to the Far East, and South Africa is the least-cost supplier to Western Europe. Table 2-1 shows that both U.S. steam coal and metallurgical coal exports in the year 1982 dropped from the previous year. By 1982, Poland began exporting both steam and metallurgical coal again and was able to supply some of its pre-1980 customers. Poland's re-entry into the world coal market and a recovery from the recent worldwide recession resulted in a 4.4 percent decrease in total U.S. coal exports between 1981 and 1982, with further declines expected [3].

Table 2-1 U.S. Steam and Metallurgical Coal Exports to Selected Countries, 1979-1982
(Million Short Tons)

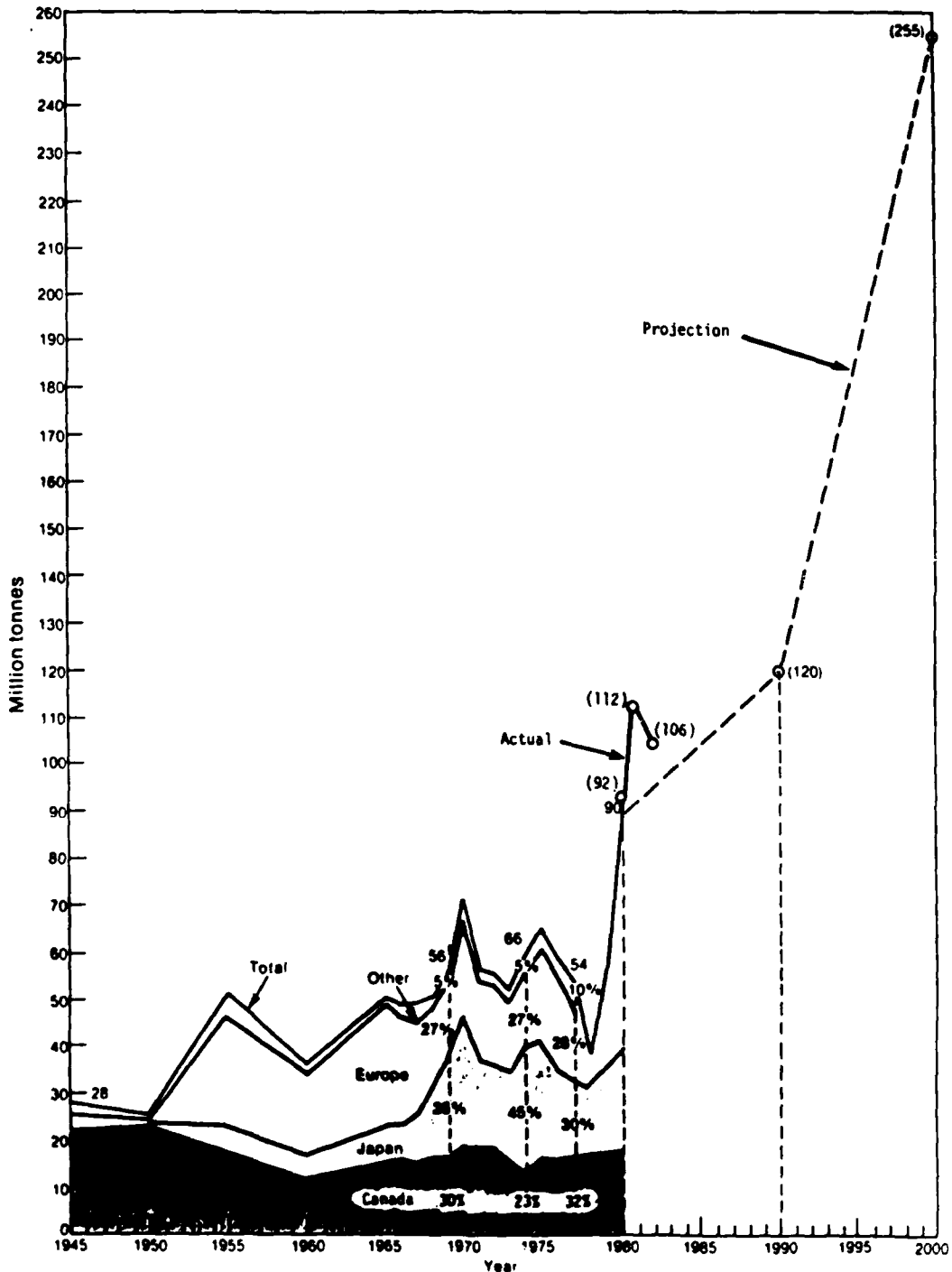
Country	Steam Coal				Metallurgical Coal			
	1979	1980	1981	1982	1979	1980	1981	1982
Japan	0.4	1.0	3.9	3.4	15.3	22.0	21.9	22.4
Canada	11.6	10.8	12.0	13.3	7.6	6.3	5.8	4.9
Italy	--	1.0	3.4	3.6	5.0	6.1	7.1	7.6
France	0.2	3.0	4.8	4.8	3.5	4.5	5.1	4.1
Belgium/Luxembourg	0.2	1.4	1.2	1.2	3.0	3.1	3.0	3.5
Netherlands	0.1	1.9	3.7	2.9	1.9	2.6	3.1	3.1
Spain	0.2	1.1	3.3	2.7	1.1	2.3	3.0	2.9
Denmark	0.1	1.5	3.3	2.7	0.1	0.2	0.5	0.1
United Kingdom	--	2.0	0.6	0.2	1.3	2.1	1.7	1.8
Brazil	--	0.1	0.1	--	2.8	3.2	2.6	3.1
Subtotal	12.8	23.8	38.2	34.9	41.4	52.3	53.8	53.5
Other	1.2	3.0	8.8	5.8	9.3	10.8	11.4	11.1
Total	14.1	26.8	45.0	40.7	50.7	63.1	65.2	64.6

-- Less than 0.05 million short tons

Note: Totals may not equal sum of components due to independent rounding.

Source: Bureau of the Census, U.S. Department of Commerce, *Monthly Report EM 522*.

Figure 2-1 History and Projection of U.S. Coal Exports



Note: Steam coal at 30 percent of total in 1980 is expected to grow to 78 percent by 2000
 SOURCES: History Coal data book; Projection-ICE Task Force with constant 1980 metallurgical coal added

A massive switchback to coal-firing presents serious long-term environmental questions. The emission of sulfur dioxide (resulting in "acid rain") problem is one of the leading issues adversely affected by coal burning. However, the oil embargos of the early 1970's and the lack of general public acceptance of nuclear technology created a void in electrical power generating capacity. Utility planners worldwide have increased their utilization of coal-fired generating capacity. However, the present oil surplus coupled with the unknowns surrounding "acid rain" legislation is having an impact on accelerating the implementation of coal-fired utility plants, particularly in the United States. However, many countries have recognized the need to switch from oil to both coal and nuclear power and have accepted the associated responsibilities of using these fuel sources in an environmentally acceptable manner.

U.S. Coal Export Terminals

Historically, the movement of coal from mines to ports has taken place over a network of railroads, inland waterways and rivers. The port of Hampton Roads, Virginia has handled 75 percent of U.S. overseas coal exports. The port of Baltimore is second with about 20 percent and the ports of Mobile, New Orleans and Philadelphia follow in capacity [2]. The anticipated increase in export activity resulted in major new projects and proposals for expansion of loading terminals. Many new projects are located in ports which have not historically handled coal. Figure 2-2 prepared by the Office of Technology Assessment indicates locations around the U.S. where coal export terminals are either being constructed or under consideration.

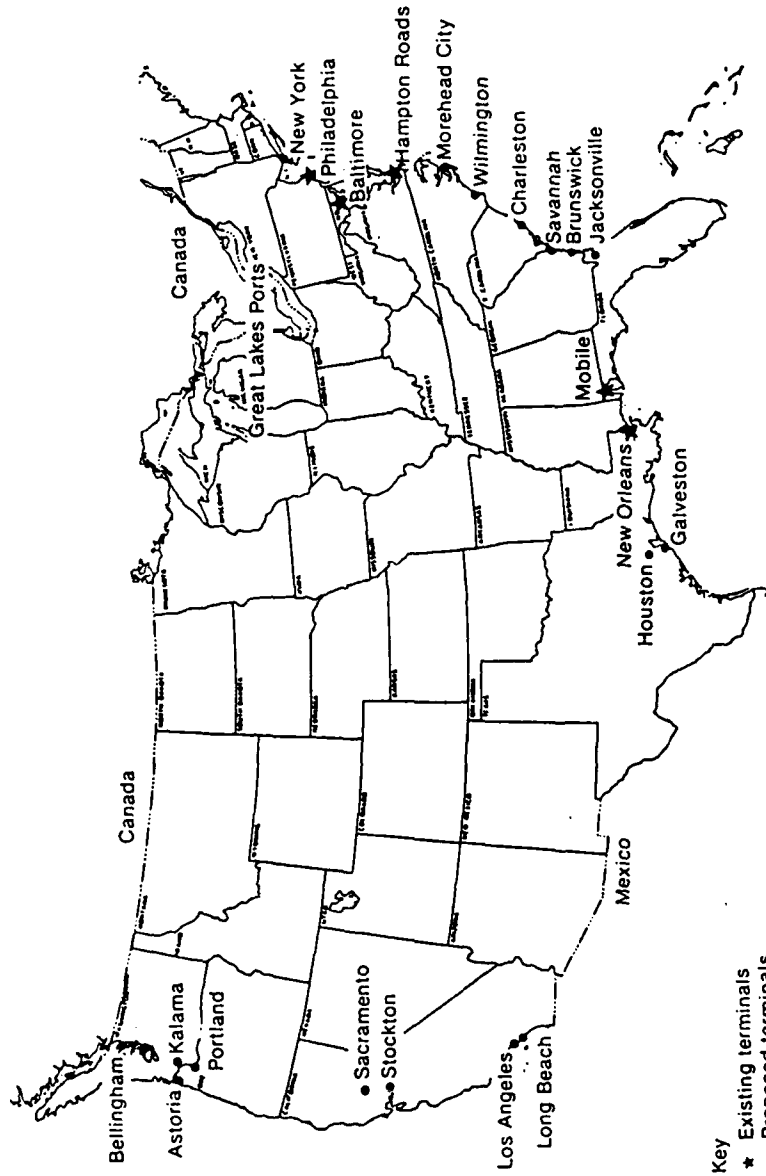
Draft limitations in U.S. ports range between 40-45 ft for the major export terminals.

Hampton Roads	45 ft
Baltimore	42 ft
Philadelphia	40 ft
Mobile	40 ft
New Orleans	40 ft

Based upon these controlling depths, the maximum size cargo load that can be handled at the terminal is 60,000 to 80,000 dwt. Coal loading facilities for ships of 100,000 dwt and over are located in Western Canada, Australia and South Africa. A number of innovative new terminals and shipping systems have been proposed such as coal slurry systems, midstream transfer-barge to ship, pneumatic pipelines, and barge carrying ships.

Coal-Fired Ships In-Service and Under Construction

Coal-fired ships are currently operating in only a few bulk trades. Table 2-2 lists the ships in-service which are included in this study. In September, 1982 Mitsubishi's Nagasaki shipyard completed the first, of a series of two coal-fired bulk carriers for an Australian shipper. Two additional coal-fired bulkers will be constructed in Italy for another Australian operator. All four ships are chartered to carry bauxite ore. The ships' main boilers are U.S. designed and licensed for construction by the shipyards. All coal handling operations from transfer to ash disposal as well as boiler combustion control, are automated or remotely controlled in accordance with Lloyds Register recommendations [8].



Key
 ★ Existing terminals
 • Proposed terminals
 SOURCE: Office of Technology Assessment.

Figure 2-2 Existing and proposed Coal Piers, Continental United States

TABLE 2-2
LIST OF COAL FIRED SHIPS SURVEYED

NAME	BUILDER	CLASS	BUILT	EMPLOYMENT	DWT
RIVER BOYNE	MITSUBISHI, NAGASAKI, JAPAN	LLOYDS	1982	BAUXITE TRADE	75,470
RIVER EMBLEY	MITSUBISHI, NAGASAKI, JAPAN	LLOYDS	1983	BAUXITE TRADE	75,470
TNT CARPENTARIA	ITALCANTIERI, MONFALCON, ITALY	LLOYDS	1983	BAUXITE TRADE	75,750
TNT CARPRICORNIA	ITALCANTIERI, MONFALCON, ITALY	LLOYDS	1983	BAUXITE TRADE	75,750
ENERGY INDEPENDENCE	GENERAL DYNAMICS, QUINCY, USA	ABS	1983	COAL COLLIER	36,250
CASTILLO DE LORCA	BAZAN, EL FERROL, SPAIN	LLOYDS	CONSTRUCTION	COAL BULK CARRIER	159,000
CASTILLO DE MONTEARAGON	BAZAN, EL FERROL, SPAIN	LLOYDS	CONSTRUCTION	COAL BULK CARRIER	159,000

A major Spanish shipowner/operator is converting two steam powered tankers to coal-fired bulkers using U.S. designed boilers. The first ship will be put into trade between Rotterdam and South Africa. The ships have been designed to trade between Europe and the United States, Australia and South America.

In the U.S., one coastal collier has been built to burn its own coal cargo. A northeast U.S. shipyard delivered a 36,000 ton coal-fired coastal collier in July, 1983 for a New England owner. A U.S. shipping company has converted two former LNG tankers to grain carriers with coal-fired boilers at a Korean shipyard. These ships have made few runs firing coal and little operational information has been made available.

SHIP OPERATIONS

This chapter summarizes service experience of coal-fired ships with respect to their operating characteristics. The major subject areas covered are:

- o Coal Bunkering Facilities
- o Fuel Quality
- o Propulsion Control Systems
- o Stack Emissions

Coal Bunkering Facilities

Growth in the volume of coal exports will also result in an increase in the average size of coal carriers. The medium size for present coal shipments is 60,000 dwt [2]. This is restricted both by Panama and Suez Canal passage widths. The largest long distance shipments of coal are around 100,000 dwt presently. This latter size could grow to 150,000 dwt by the year 2000 given a steady increase in the volume of coal shipping. There is considerable uncertainty in the growth rate of steam coal shipping requirements. However, the average size of bulk carriers in general may increase because of economics of scale even without rapid increases in coal shipping. The draft and beam restrictions imposed by the Panama Canal limit sizes to about 50,000 - 80,000 dwt. Ships too large for the canals must use routes around the Capes of South America and South Africa. These latter ships must take advantage of scale and use bulk ships of 100,000 - 150,000 dwt.

The worlds most active coal export terminals are listed in Table 3-1. Additional port facilities required for bunkering ships at ports that already export coal as cargo are relatively small. The least costly approach is to design the ships to load at the same terminals that load the cargo. If this is not practical, a separate self-discharging bunkering barge or dedicated berth with coal handling equipment can be constructed. Ship operator studies show that two to four coal-fired bulk carriers regularly loading bunkers can justify the installation of a dedicated terminal [4]. This is equivalent to 50-95% utilization of a single berth.

Several approaches have been taken by existing coal-fired shipping operations. The Australian ships share a dedicated berthing facility. Coal from unit trains arriving from open pit coal mines is unloaded onto a coal pile. During unloading coal is transferred by truck to the marine bunkering terminal. Coal is run through a screen and crusher during this unloading process. A dense-phase transfer system takes the coal from a 2000 short ton storage hopper for delivery aboard the ship. No screening and crushing is accomplished aboard ship.

The opposite approach is used for the existing New England collier and the Spanish bulk carriers under construction [5,6]. Steam coal will be loaded from a conventional terminal. The ships burn cargo coal and have the ability to transfer coal from coal cargo/bunker holds to the daily use hoppers in the machinery space. Since cargo coal normally contains up to 50-60% fines, but has been reported as high as 70-90% fines, the operators have to "shop" for their load of coal on the basis of lower fines content rather than lowest

TABLE 3-1

EXPORT TERMINALS FOR STEAM COAL

U.S. East Coast	Philadelphia, PA Baltimore, MD Hampton Roads, VA Charleston, SC
U.S. Gulf Coast	New Orleans, LA Galveston, TX Mobile, AL
Europe	Gdansk, Poland
South Africa	Richards Bay
Australia	Gladstone, Queensland

market price. An on-board crusher has to be used as well as a magnetic separator to transfer coal to a bunker for fuel. The colliers utilize a self-unloading mechanical crane for transferring coal from cargo holds to the coal bunker. The Spanish bulk carriers will incorporate a combined mechanical and pneumatic system for transferring coal from two forward cargo holds to the daily use hoppers. A screen and crusher is included in each hold prior to entry into the dense-phase coal transfer system.

Fuel Quality

Boilers of coal-fired ships from the first Atlantic crossing of the SAVANNAH in 1819 to just a few decades ago were fed manually by groups of stokers called "black gangs". During the last several decades two types of automatic coal handling systems have been developed; 1) pulverizers or 2) mechanical stokers which throw the coal onto the boiler grate [1].

Shore-based utility boilers have used pulverized coal since the early 1920's. The pulverizer and burner system must be designed for a specific coal. The crusher or pulverizer grinds the coal to face powder consistency and the burner is designed to fire the coal in suspension much like oil firing. Several notable vessels employed pulverized coal installations such as the ore boat SS CHAMPLAIN and an early SS FRANCE liner. Besides the disadvantage of being designed to use a specific type of coal, pulverized coal leakage can represent a serious safety hazard. Coal particles in air suspension can result in "dust" explosions of large magnitude. Lloyds Register [8] notes that several explosions have been reported on the Rhine River coal barges which haul pulverized coal.

Mechanical stoker-fired boiler designs have been selected for all of the new generation of coal-fired ships because they will more readily accept fuel specification changes and do not represent a safety hazard. The lowest grade of coal which can be handled by this equipment is called "steam coal" or stoker grade bituminous. The coal varies in size from 1-1/4" to powder with fines* or powder representing a maximum of 40% (normally). The Australians have reported receiving loads of bunkered coal aboard ship with fines (powder) content significantly in excess of 50%. Fines can consist of particles with face powder consistency. They are generated in the mining, shipping and crushing process before the coal reaches the ships bunkers. Steam coal purchased from Hampton Roads, Baltimore and Philadelphia can contain up to 50-60% fines. In addition, on the U.S. East Coast, coal must be washed at the mine to remove sulfur.

The operators identified several major problems caused by the fuel being consistently "off-specification". Segregated coal* entering the boiler results in unstable combustion conditions. The result is fluctuations in the steam generation rate. Several operators maintain that a majority of their startup difficulties were caused by severe segregation in the coal bunkers. These include:

- Pipe blockages in the coal transfer system
- Tramp iron* not picked up by magnetic separators shoreside.
- Shear-pin failure in coal feeder drivers due to jamming with oversized material.

* Words marked by an asterisk (*) are defined in Appendix B.

- Overload of ash transfer system crushers due to presence of oversized rock and clinkers* generated in the boiler.
- Blockages in the ash transfer system.
- Burning coal fed through the ash system.

Many blockages in the coal transfer system have been caused by a combination of low moisture content and heavy fines concentrations. Segregation of the coal in the bunkers results in large volumes of powder like fines passing through the coal feed system into the boiler. The coal feed system and the boiler stoker (throwers) were designed to handle a homogeneous mixture of nuggets and fines. When heavy concentrations of fines pass through the system, the moisture content of the coal becomes a much more significant factor. Dry, caked slugs of coal fines have tended to jam pneumatic transfer systems. Lowering the air pressure of pneumatic coal transfer systems reduces segregation.

Segregated coal entering the boiler has resulted in another operating problem. Unstable combustion conditions in the boiler can lead to a fluctuating steam pressure generation rate as well as irregularities in the ash bed thickness. A uniform ash bed is necessary to insulate the boiler grate. The fluctuating steam rate is a potential hazard while maneuvering in close quarters. Engineers indicate that maintaining "engine r.p.m." within one revolution is necessary during canal transits.

Propulsion Control Systems

Regulatory bodies have basic requests for automated steam power plants (UMS or ACCU). These requests were developed for oil fired steam plants. With the change from oil fired to coal-fired boilers, these regulatory bodies have developed additional requests summarized in Table 3-2 for Lloyds.

To maintain their competitiveness with oil-fired steam and diesel propulsion, coal burning boilers must be capable of operating at least part of each day unmanned. Lloyd's Register will class all of the Australian and Spanish flag coal fired propulsion plants. All coal-fired ships currently operating which were classed by Lloyds have the UMS (Unmanned Machinery Space) notation. Lloyd's has published a set of guidance notes [8] on the use of coal at sea. Section 6 of the notes describes requirements for control engineering systems. The notes refer to Part 6, Chapter 1 of the Rules and Regulations for the Classification of Ships, Lloyds Register. Section 4 applies to requirements for UMS spaces. Coal fired ships have additional requirements which are summarized in Table 3-2 for remotely controlled or automatic operations.

The U.S. ships currently in operation have been classed to American Bureau of Shipping requirements. They have not been operated with unattended control systems. ABS published its "Guide for Ships Burning Coal" in 1980. U.S. flag certification requires compliance with this guide as well as all other applicable ABS and Coast Guard regulations.

Special Crew Training. The training procedure used by some operators when introducing a new ship into the fleet may be adopted for use on coal fired ships. Using this program, all senior engineer officers would be trained in shore power plants using coal fired boilers and the junior engineer officers would be trained on board under the supervision of senior officers. When an officer is going on vacation, the relieving officer would come on board

TABLE 3-2

LLOYDS' CONTROL REQUIREMENTS FOR COAL-FIRED STEAM PLANTS

Item	Alarm	Note
Drum water level	Low	Combustion air; coal spreaders and/or any alternative fuel supply to be shut off automatically.
Coal feed plant	Failure	-----
Daily service hopper level	High/Low	-----
Primary combustion air system	Failure	Coal spreaders to be stopped automatically.
Secondary combustion air system	Failure	-----
Coal supply controller (if separate from spreader)	Failure	Per controller
Spreader drive	Failure/ Overload	Per drive
Grate drive	Failure/ Overload	Per drive
Localized overheating of the grate	Excessive	-----
Induced draught fan	Failure	Coal spreaders to be stopped automatically.
Ash disposal system	Failure	-----
Smoke emission	High	-----

NOTE - Interlocks are to be provided to prevent the burning of oil fuel unless dampers in the gas passages of uptakes have been securely locked in the fully open position.

TABLE 3-3

AUSTRALIAN BAUXITE CARRIER MANNING

	Accommodations	Current Manning
<u>Officers</u>		
Master	1	1
Chief Officer	1	1
2nd Officer	1	1
3rd Officer	1	1
Radio Officer	1	1
Shipwright	1	-
Ch. Eng. Officer	1	1
2nd Eng. Officer	1	1
3rd Eng. Officer	1	1
4th Eng. Officer	1	1
5th Eng. Officer	1	-
Electrical Officer	1	1
	<u>12</u>	<u>10</u>
<u>Catering Dept.</u>		
Chief Steward	1	1
Asst. Steward	3	1
Chief Cook	1	1
2nd Cook	1	1
Crew Attendants	<u>2</u>	<u>-</u>
	<u>8</u>	<u>4</u>
<u>SUA & Engine</u>		
Bosun	1	1
Bosun's Mate	1	1
ABS	5	5
O.S.	1	1
Donkeymen	<u>3</u>	<u>3</u>
Greasers	11	11
TOTAL	31	25

at least one week in advance. At present there is no special license requirement by USCG for coal fired propulsion plants.

Manning. Requirements for manning coal fired ships have not been identified as being significantly more labor intensive than oil fired steam plants. One operator indicated that an additional engineering officer was required to cope with the extra workload on his coal fired ship. However, there were indications that this additional work would subside when the initial "teething" problems were fixed and modifications installed.

Proposed and current manning levels for a 75,000 dwt Australian bauxite carrier are shown on Table 3-3. The operator indicated that manning levels in each department are more directly determined by standing union agreements than workload.

A U.S. built and operated coal collier has had similar experience. Unattended operation of their plant is not presently feasible. One engineer must be located in the engine room at all times. The ship is crewed for 23 but presently has one additional 3rd engineer. They have had no significant labor problems and the crew likes the coal fired plant. The ship uses a two-crew rotation system. Unlicensed crew work 30 days on, 30 days off. Licensed crew work 45 days on, 45 days off.

Ship Maneuvering Response. A coal-fired spreader stoker boiler has inherent time lags because of the nature of the fuel feed system. However, the opinion of the masters operating the Australian ships is that the actual response does not adversely impact the maneuvering characteristics of the vessels. Dockings in Gladstone harbor are routinely made with the ships fired on coal with minimal tug assistance. These ships have no bow thrusters installed. The 36,000 dwt U.S. collier has both fore and aft bow thrusters. Baseler [5] reports that this ship meets all U.S. Coast Guard requirements for posting of maneuvering data. The thrusters proved effective on trials in turning the ship at speeds up to six knots.

Coal-fired boilers are estimated as having response times about 60% as fast as oil-fired boilers. Oversized condensers are sometimes fitted to allow steam dumping to rapidly reduce the speed of the ship. To maintain overall propulsion system response equal to an oil-fired plant, additional control system design features must be developed.

The response achieved in actual practice is better than expected. The design approach currently in use involves limiting the turn-down ratio to between 50% and 25% of the maximum evaporation rate. This insures that when the ship is steaming at low power the evaporation rate is sufficiently high to provide acceptable response to "Full Ahead" or "Full Astern" demand from the bridge. Varying amounts of steam must be dumped to the condenser during maneuvering to keep the boiler evaporation rate constant. Higher turn-down ratios also result in lower fuel consumption.

During normal steaming, dumping is not generally required. The turn-down ratio obtained by adjusting the grate speed handles normal load fluctuations. However, steam dumping ability is essential for ship maneuvering and for preventing safety valve lifting. No slagging due to prolonged operation at partial load has been observed in the boiler combustion chamber. Large radiant surface in the boiler keeps the combustion air temperature low.

Stack Emissions

Stack gas nuisance problems have existed since the first coal fired steam plants went into service. Without proper care for sizing of the stack height and shape, gases will be directed down over the deck during certain relative wind conditions. The problem of carrying soot from coal fired stack gases is of special concern [9]. The era of the large passenger liners resulted in many stack design improvements. The universal acceptance of oil-fired boilers resulted in the virtual elimination of soot fallout problems on commercial ships.

The re-introduction of coal firing will require that closer attention be paid to this aspect of ship design once again. Since the soot generation rates of coal-fired boilers are higher, inadequate stack design can result in excessive soot deposits and injection into ventilation inlets on one coal-fired ship.

The stack casing shape and height must be carefully selected for each new ship design. Tried and proven empirical design techniques as well as model study verification are often used to assure a sound design. One operator has indicated that it was necessary to modify their stack design after their coal-fired ship was in service. Typical modifications involve either raising the stack height, increasing the exit velocity or modifying the stack shape. Generally, increasing the exhaust momentum allows the soot and flyash emissions to clear the deck with the ship underway. A secondary problem, caused by inadequate stack design in this case, was injection of exhaust gas into ventilation inlets. Fresh air makeup for ventilation systems did not initially have filter elements. Filters have been refitted to the air inlets. The stack extension has also reduced inlet air contamination.

COAL HANDLING SYSTEMS AND BUNKER DESIGN

This chapter summarizes the unique characteristics and service experience of coal-fired ships with respect to their required design features and operational experience. The major subject areas covered include:

- o Coal storage bunkers
- o Pneumatic dense-phase coal handling
- o Design trends in coal handling

Coal Storage Bunkers

In developing the design of the coal storage bunkers as well as the daily service hoppers, a significant amount of model testing was conducted. Coal supplied from shoreside is bunkered in the coal storage hoppers on board. From there, coal is transferred by a pneumatic system, i.e., Denseveyor coal handling system (see Fig. 4-1, 4-2), to the daily service silos according to the boiler consumption. These tests indicated that:

- o Slope of stainless steel clad bunker walls should be at least 65-72 degrees from horizontal.
- o Agitators or air carriers should be used to break bridges or "hang-ups" near outlets.
- o Trimming and feed outlets must be designed to avoid "peaks"* and "troughs".* The use of mechanical screw feeders has been universally successful in avoiding these problems.
- o Heavy soaking of friable coal such as Australian Callide will result in fines caking and hanging up on the bunker walls.
- o Segregation in the bunkers due to malfunctions in dockside loading equipment has lead to unstable combustion in the boiler. The resulting fluctuating steam rate is potentially dangerous when maneuvering.

The coal bunkering and boiler feed system in the Australian ships was designed around the mass flow principles espoused by Jenicke of the United States. Additional research work was conducted at the University of Wollongong, in Australia. Model testing using Jenicke's theories was carried out. The slopes of the chute walls in the ships are angled at 72 degrees. Coal chutes feed into a single conical catcher, and subsequently, the coal falls into one of the dense-phase units. The chutes have stainless steel cladding, in contrast to the bunker walls, which are Corten steel with an epoxy coating.

Coal Bunker Fires. Australian operators have experienced bunker fires. Various methods have been adopted by ship owners to detect fires in coal storage holds. Some detection methods are listed below:

- o Carbon monoxide monitors
- o Air pressure sensors
- o Gas sniffers (methane gas detectors)
- o Insulation bunker hold walls
- o Adequate forced ventilation

Figure 4-1
Macawber Model 8
Denseveyor
Coal Handling System

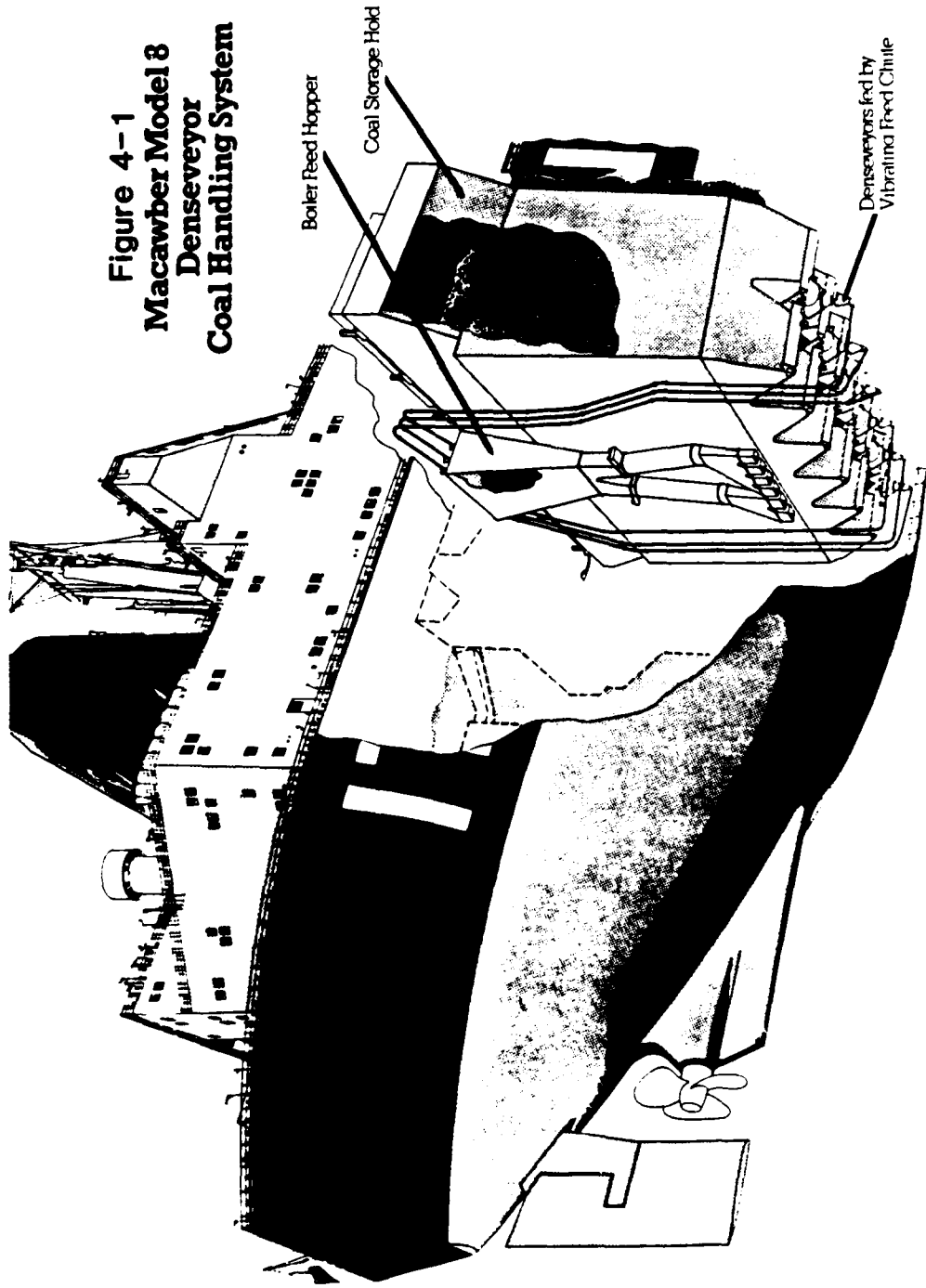
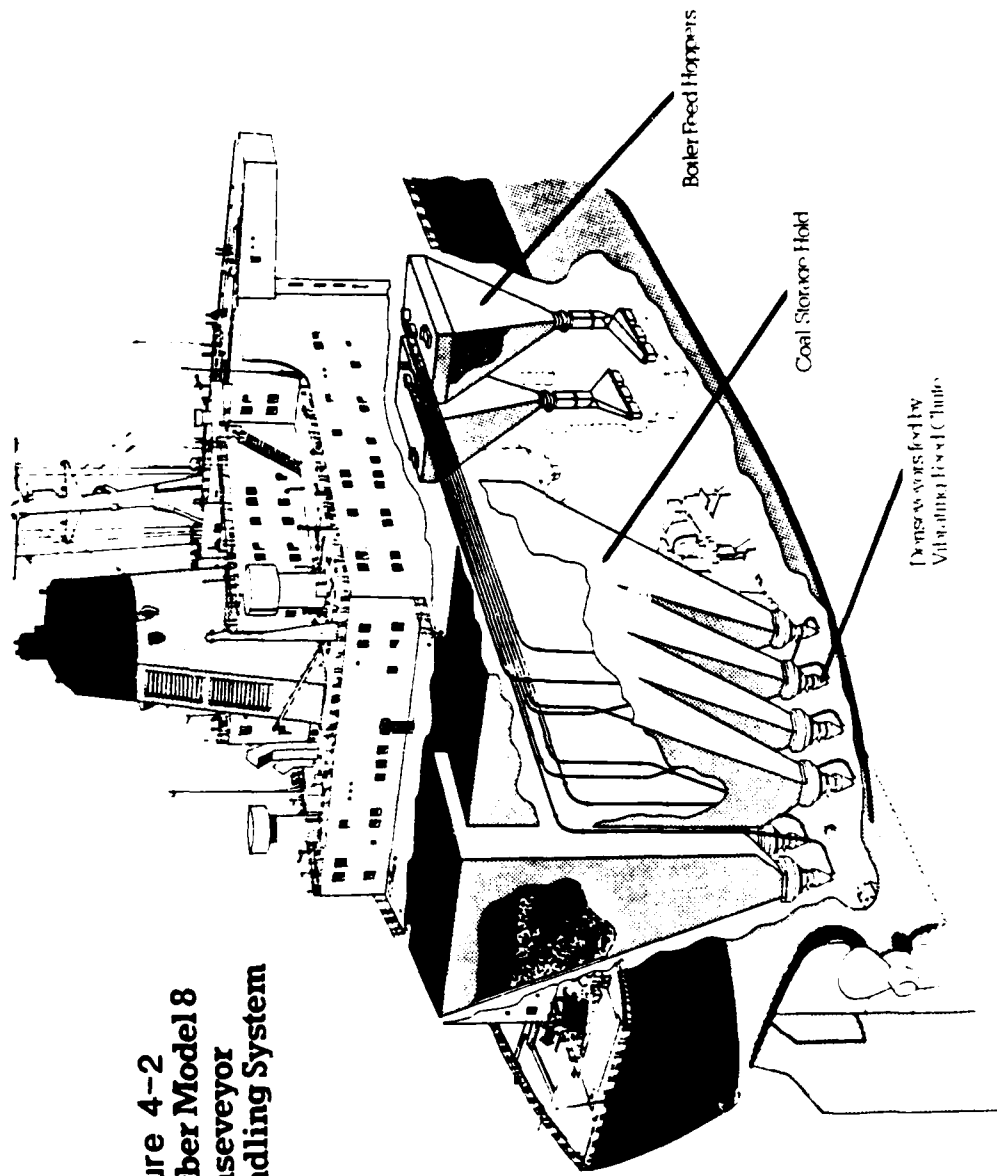


Figure 4-2
Macawber Model 8
Denseveyor
Coal Handling System



Carbon monoxide monitors are installed at various points within the coal bunker. These monitors allow identification of combustion coal within the bunker. Early predictions of spontaneous combustion of the coal have proved invaluable. Experts identified the possibility of ignition at temperatures as low as 100 degrees Fahrenheit.

During the design stages, they had considerable discussions with Lloyds Register concerning the need for a fire protection system. Lloyd's original requirement was for the utilization of a CO flooding system. Not all owners, however, agreed to this requirement. One operator's compromise with Lloyds was to install a 10" seawater line near the top aft end of the coal bunker. This line can be used to spray seawater into the coal bunker. However, since there is no way to seal off the chutes at the bottom of the bunker, complete flooding is not possible. Carbon monoxide monitors were installed at six points within the coal bunker. Explosion blow-out lids are also fitted on some ships.

In-service, however, ships crews have developed very effective methods for monitoring and controlling these fires. Once an alarm is sounded, the crew manually stops the sequencer which alternately selects coal from one of each of the coal chutes. They concentrate upon removal of the hot spot* by only transferring coal from that coal chute from below. In this manner they have successfully continued to operate the plant when hot spots have occurred in a coal bunker.

Pneumatic Dense-Phase Coal Handling

Transfer of coal from the bunker to the daily service hoppers is achieved by a pneumatic system for coal fired ship designs. Though the pneumatic systems consume more power than mechanical conveyors, they have been chosen for comparative ease of operation and maintenance. The first shipboard system of this type has been designed and supplied by an engineering firm in the United Kingdom for use on Australian ships. Air for the pneumatic system is supplied by compressors installed on board. Reciprocating high pressure compressors proved to be the worst maintenance item. Centrifugal air compressors are preferred for the transfer of coal. The air receivers should have sufficient reserve volume to maintain steady pressure of 80-100 psi in the system.

Alternate mechanical types investigated were:

- o flexible belt
- o drag-link
- o bucket conveyor

The pneumatic system allows transfer of solid fuel through piping essentially similar to that used for liquid fuels. Pneumatic systems are grouped into two main types - lean phase and dense phase. The flow velocities of coal lean phase systems are much higher than dense phase and use larger volumes of transfer air per unit of coal. In dense phase transfer systems the coal is moved at lower velocity in a series of "slugs" through the piping. Typical flow velocity of coal in dense phase systems is about 7-8 m/s as opposed to 30-40 m/s in lean phase system. Lower velocity reduces erosion/corrosion of components.

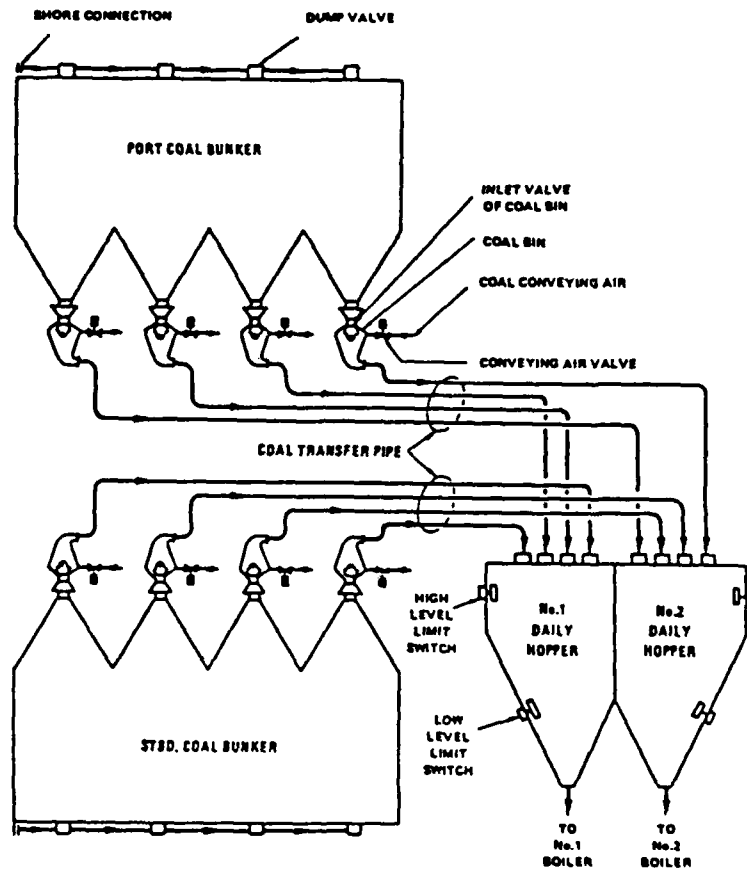


Figure 4-3 Typical Coal Transfer System

Dense phase pneumatic coal transfer systems have been chosen for use in all of the coal fired ships in-service. Three different manufacturers' designs have been used. The dense phase system operating cycle is schematically shown on Figure 4-3. Dense phase pneumatic systems use low air volumes and thus smaller compressors and venting system.

The dense-phase pneumatic conveying concept is based upon transportation of materials in a compacted slug at low velocities. Traditional pneumatic conveying systems depend on using the air to fluidize the particles to reduce friction. There are several unique properties of dense phase transfer systems. They operate at lower velocities with lower air consumption. This type of conveying is most useful for transferring bulk abrasive materials, wet materials, including coal and grains with a wide particle size distribution.

Standard systems are designed to accept coal lump sizes up to 3 inches in diameter. Coal can be mechanically transferred to a reception gravity hopper. Coal supply is gravity-fed to a vibrating chute. Then the system takes over and vibro-feeds the coal through the inlet valve to the dense phase unit.

Dense-phase systems are available for pipeline sizes of 4" through 12" to pump coal at rates up to 100 tons/hour and distances up to 600'. Manufacturers claim that the largest size units can handle up to 100 tons/hr with a 12-inch transfer pipe up to a distance of 600 ft. (200 meters). The design velocity of the transfer system is 50 ft/sec. At the maximum transfer rate 800 cfm of 100 psi (7 bar) air is required. This consumes about 160-170 hp in a rotary screw type centrifugal compressor.

Pipe material for coal handling systems is usually Schedule 80 welded steel with Nihard bends only. Straight sections of pipe should last 6 or 7 years. Bends should last 2 or 3 years. For this reason removable sections should be used which can be easily replaced without dismantling the pipe. Refer to Table 4-1 for a range of recommended sizes.

Pneumatic dense-phase coal handling systems experienced numerous jams, when initially installed in coal-fired ships [10]. The design of the coal transfer system requires a lift of the coal from the bottom of the coal bunker on the tank tops to the daily use hopper located above the boiler. Coal slugs consistently jammed at the bottom of this rise in the transfer piping. The problem is caused by several design factors which vary on each ship. Remedial action taken by operators and new design features are discussed later in this section.

Transfer systems have also been blocked by dry coal. Moisture content of Australian Callide and Blackwater coal ranges from 5 percent to 15 percent. Dry callide coal (moisture content 2%) has resulted in pipeline blockage. The average specified for design purposes was 6.5 percent. However, one in-service problem during early operation of the vessel indicated that coal was much too dry. The transfer system must be operated with a minimum moisture content of 10 to 12%.

Dry bunkers have led to pipeline clogging between the output of the dense phase units and the tops of the ready-to-use coal hopper. A temporary fix for this clogging has been to insert openings at the top of the line and manually spray water or additional compressed air into the vertical piping. This may be added as a standard feature in future designs. The ships have experienced no problems with very wet coal. In fact, they state that coal which is almost

TABLE 4-1

DENSE PHASE COAL HANDLING PIPE SIZE REQUIREMENTS

Pipe mm	Diameter		Coal Size (Max)	
	inches		mm	inches
100	4		32	1-1/4
125	5		40	1-3/8
150	6		48	1-1/2
220	8		60	2-1/4
300	12		80	3-0/0

BOILER DESIGN AND ASH HANDLING SYSTEMS

This chapter summarizes the unique characteristics and service experience of coal-fired ships with respect to their boiler design and ash handling systems. The major subject areas covered are:

- o Boiler design and arrangements
- o Ash transfer and storage
- o Overboard ash discharge

Boiler Design

Operators have experienced a number of teething problems with coal-fired boilers. The major areas of difficulty reported have been:

- High flyash generation, excessive soot blowing and dust collection requirements.
- Inadequate access for machinery maintenance.
- Failed stoker drive assemblies.
- Re-design of grate drive to control speed.

Flyash Generation and Control. Particular attention must be paid to the boiler design with respect to flyash generation rates. Experience of Australian operators indicates a higher than expected ash generation rate. This has been due to both high ash content in the coal as well as production of a higher ratio of flyash to bottom ash than expected. One operator chose to initially segregate flyash and bottom ash into separate hoppers. This was partly due to the potential economic value of flyash for its use in a variety of industrial processors. Due to the much larger than forecast volume of ash, this arrangement had to be abandoned in favor of storing all ash in common hoppers prior to discharge at-sea. It is highly recommended that bottom ash storage capacity for 24 hours at full power be included in the ash hoppers.

Another operator using a single boiler design, found it necessary to retrofit a flyash collection system to capture burning cinders prior to entry into cyclone dust separators and secondary filters. Originally, a superheater cavity hopper collected unburned coal particles after combustion gas passes the first set of superheater tubes. Particles drop out of the gas stream due to their deceleration as they exit the front superheater. An eductor is fitted into the downtake pipe which uses overfire air to propel the cinders into the lower furnace. It was necessary to add a second flyash collector after the second bank of superheater tubes.

In general, operating experience has shown that single stage mechanical dust separators have proven inadequate for flyash cinders. In addition to the double collection hoppers within the boiler, both a primary and secondary centrifugal separator as well as a final bag filter, are recommended for ensuring clean air discharge which will meet most port authority regulatory codes. It is recommended that more sophisticated multiple-stage dust collector systems be used in lieu of single-stage mechanical cyclones to meet in-port clean air regulations and prevent excessive particulate disbursement. Operators with these systems indicate they routinely meet Ringleman No. 2 opacity requirements.

slurried can be handled adequately by their coal feed system. Ingestion of stone, wood and steel bands has occurred. In most cases foreign matter has passed completely through the coal feed system, over the firing grates and into the ash system without apparent damage.

Marine applications experience has also uncovered several unique failures of the equipment for which the manufacturers have a fix and retrofit program. In particular, Australian operators have consistently loaded coal with low moisture content. To correct this problem the coal bunker has been dosed with excess water by sprinkler heads or hose bibs above the dense-phase unit. The result is that the inlet valves have stuck on occasion. The diagnosis was that a bushing in the shaft of the inlet valve shaft assembly was swelling, and this resulted in freezing the swivel head. Both the bearing material and packing glands have been changed, and a retrofit kit for the existing units is being shipped for all marine units.

Pipe clogging in the coal transfer system has also been reduced by a variety of new methods. One U.S. operator found that insertion of a PVC pipe liner reduced friction sufficiently so that occurrence of blockages were sharply reduced. Another design feature which is now offered which will assist in moving dry coal is the automatic line clearing system. The system consists of static pressure sensitive valve assemblies which are located every 2 or 3 meters along the transfer system. The valves are piped to one another in "piggy-back" fashion. The input air supply comes from the previous valve and the output goes to the next valve along the pipe. When a dense-phase coal slug is stuck, the system senses the pressure buildup behind the slug and releases air to jar loose the slug. The automatic line clearing system will be installed on new bulk carriers being constructed in Spain as well as being offered for land-based applications with particularly long horizontal pipe runs.

Design Trends in Coal Handling. The new coal handling arrangement marries both the pneumatic and mechanical systems. It is obvious that the mechanical portion of the system is primarily used at the bunker hold and eliminates the need for multiple configured (sloped) tanks; thereby reducing the number of pipes and denseveyors.* The pneumatic portion of the system is primarily used for moving the coal relatively long distances. This combination of mechanical and pneumatic systems improves interior machinery space and bunker design.

One example of a combined mechanical and pneumatic dense-phase system is a new Spanish bulk ship design. In that design screw conveyors are used to feed a mechanical drag-type continuous loop conveyor. The screw conveyor has also been used successfully in service on Australian coal-fired bauxite carriers. An Italian manufacturer supplies the units. The mechanical loop conveyor then feeds into a screen and crusher assembly above the dense-phase units for transfer back to the daily use hoppers in the engine room.

Pre-heating of the combustion air improves the cycle efficiency, but is hazardous due to the abrasive nature of the combustion gas. However, there is a limit of how much the combustion can be pre-heated. The 130 degrees Fahrenheit maximum was determined by Combustion Engineering and Detroit Stoker. This combustion air temperature helps to keep the grate below the acceptable maximum grate temperature of 300 degrees F.

One U.S. ship operator reported experiencing excessive soot blowing requirements for their boiler. They had to modify their soot blowing equipment to correct this problem. A positive pressure in the boiler casing caused excessive ash leakage in the engine room during the soot blowing operation.

Machinery Arrangement and Ventilation. Machinery arrangements with adequate access for maintenance, particularly adjacent to the stoker-throwers, and near bends in the ash system piping, are required. One poor example identified was a narrow separation between a coal bunker bulkhead and the spreader-stoker thrower mechanisms on the boiler front. In this ship the distance was only a little over one (1) meter, about 4 feet. This narrow space has been a problem due to the requirement for crew to manually operate within that small space. At times, they have had clinkers the "size of a volkswagon". When these large chunks of coal appear, it is necessary to get a slicer* into this space to break them up. Also, this narrow space required additional insulation of the coal bunker wall with mineral wool to prevent radiation heat transfer from the forward end of the boiler to the coal bunker. It was feared that this could create hot spots within the bunker and subsequent coal ignition.

Two operators have reported problems with inadequate machinery space ventilation. The high heat loads are caused by elevated external boiler casing temperatures. In some cases, these temperatures have exceeded 150 degrees F. In both cases, the capacity of the machinery space ventilation fans were comparable to oil-fired plants. There was insufficient room for installing more fans and ductwork. The additional electrical load and ductwork volume would be a problem. The solution was to allow cross ventilation in the engine room by providing openings in the main deck directly over the boiler.

Coal Feed System. Coal burning is fed with mechanical stokers by completely automatic systems. Mechanical stokers have been in use in shore-based plants and U.S. Great Lakes ships for many years. Typical designs of the spreader stoker use a continuous discharge system with a traveling grate mounted in the bottom of the boiler (See Figures 5-1 and 5-2) [11,1]. Standard stoker and grate assemblies appropriate to boiler manufacturers' designs have been in-service for several years.

Coal is transferred from the daily use hopper (service bunker) by gravity feed to the stoker. Some type of shut-off valve is usually provided at the entrance to the stoker to isolate the daily use hopper. Coal is fed into the boiler and burned on the stoker grate. The "stoker" consists of two major components: the coal spreader units and the rotating grate.

A typical coal spreader design is shown in Figure 5-3 [12]. The coal drops from the feeder onto a reciprocating fuel feed plate. It is pushed into the rotor housing where the rotating rotor blades "throw" the coal into the boiler furnace onto the rotary boiler grate. The rotor runs at constant speed but can be adjusted to give the correct throw distance. The heavier pieces of coal are pitched to the opposite end of the boiler grate. The coal burns while

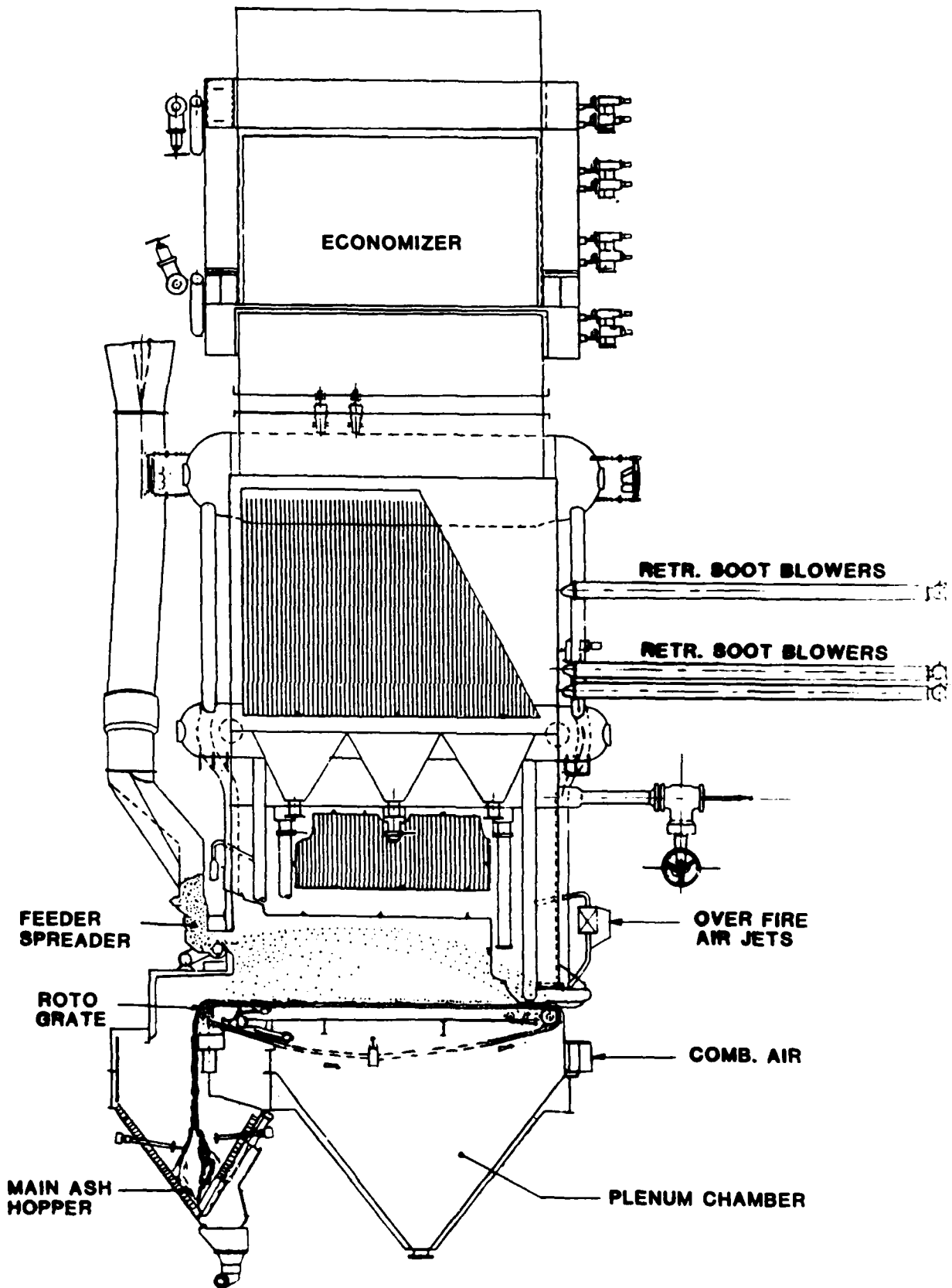


Figure 5-1 Stoker Fired Marine Boiler
(Example 1)

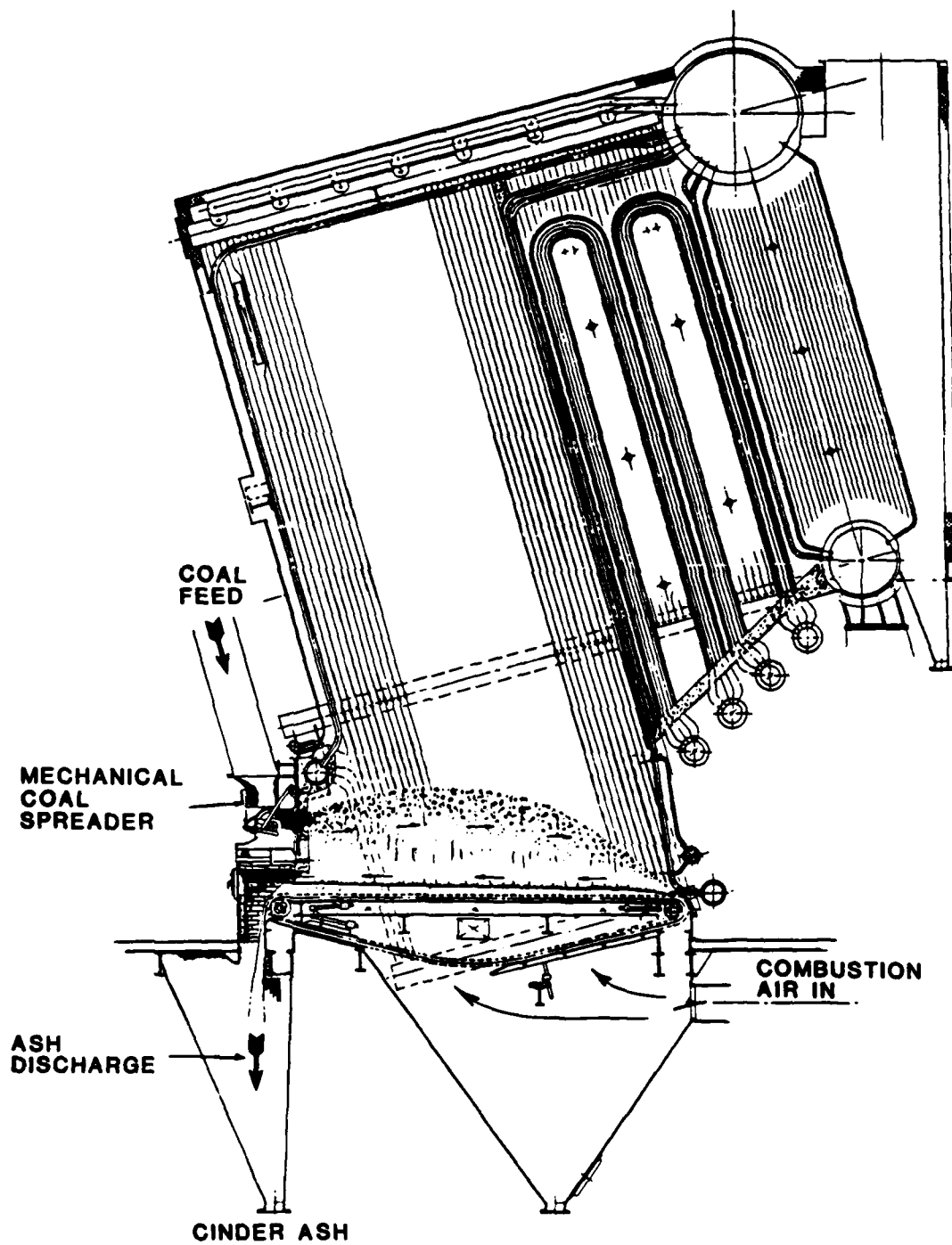


Figure 5-2 Stroker Fired Marine Boiler
(Example 2)

the grate moves toward the feeder unit. Coal fines burn in suspension and never reach the grate. When excessive fines are fed into the boiler by the thrower all the fines are not completely burned before being carried into the superheater. Another problem experienced in-service when this occurs is that the ash bed on the grate is not maintained. The ash bed insulates the grate metal from the hot coals. The entire grate area must be uniformly covered by ash. Thus, the impact of size segregation of the coal feed system is evident.

One failure of a feeder rotor has been experienced. A shear pin in the rotor assembly failed due to foreign object injection into the rotor feeder. The situation was corrected by changeout of the entire feeder unit. A spare feeder unit is now kept on-board that ship, but instead to adjust the grate speed to obtain the required turn down ratio.

Boiler Grate Design. The grate holding the ash bed is made up of grate bars pinned and connected to a chain at each end. Multiple grate sections are locked together so that they are forced to move in parallel. Several of the ships in-service are designed to allow a portion of the feeders and grate to be shut-down while the remaining grate sections are in-use. The idea was that this feature would be used for in-port operations. Operators have preferred not to shut-down part of the grate in-port.

Several ships have incorporated the split grate design with a 4:1 turn-down ratio. Two-fifths of the grate is driven by a separate motor and chain drive system while the remaining three-fifths can be operated separately. In normal, at-sea operations, both grate sections must be synchronized to operate at the same grate speed. In practice, however, a much lower turn-down ratio of up to 8:1 was achieved. The engineers preferred this method of control over shutting down part of the grate. They noted that stabilizing the boiler flame is a major consideration when shutting-down or starting-up a section of the grate. One of the reasons cited was the long lead time required for combustion conditions in the boiler to stabilize after the grate speed has been changed. Fine tuning of the thrower speed, grate speed and uniformity of the fuel mixture and feed rate is required for balanced operation. The relatively short turnaround time in-port does not allow sufficient time to re-tune the system. The preferred method has been to slow the grate speed down. Several ships have been modified to allow slower grate speeds than originally designed.

One "grate drive failure" has been reported during operation of a coal-fired boiler. The problem occurred during sea trials. Several cotter pins were found missing on the stoker chain. The grate bars jammed after retaining washers fell off. The problem was repaired by on-board crew.

Ash Transfer and Storage

The principal alternatives with respect to ash handling include use of a pneumatic system, either lean-phase or dense-phase, or a vacuum system incorporating either wet or dry ash transfer. The dense-phase principle has successfully been used in land-based installations. Refer to Figure 5-4.

Manufacturers have supplied more than 50 dense-phase ash handling systems throughout the world. There are no marine installations of dense-phase ash handling systems to date. One major advantage claimed would be the reduction in transfer velocity possible with dense-phase systems.

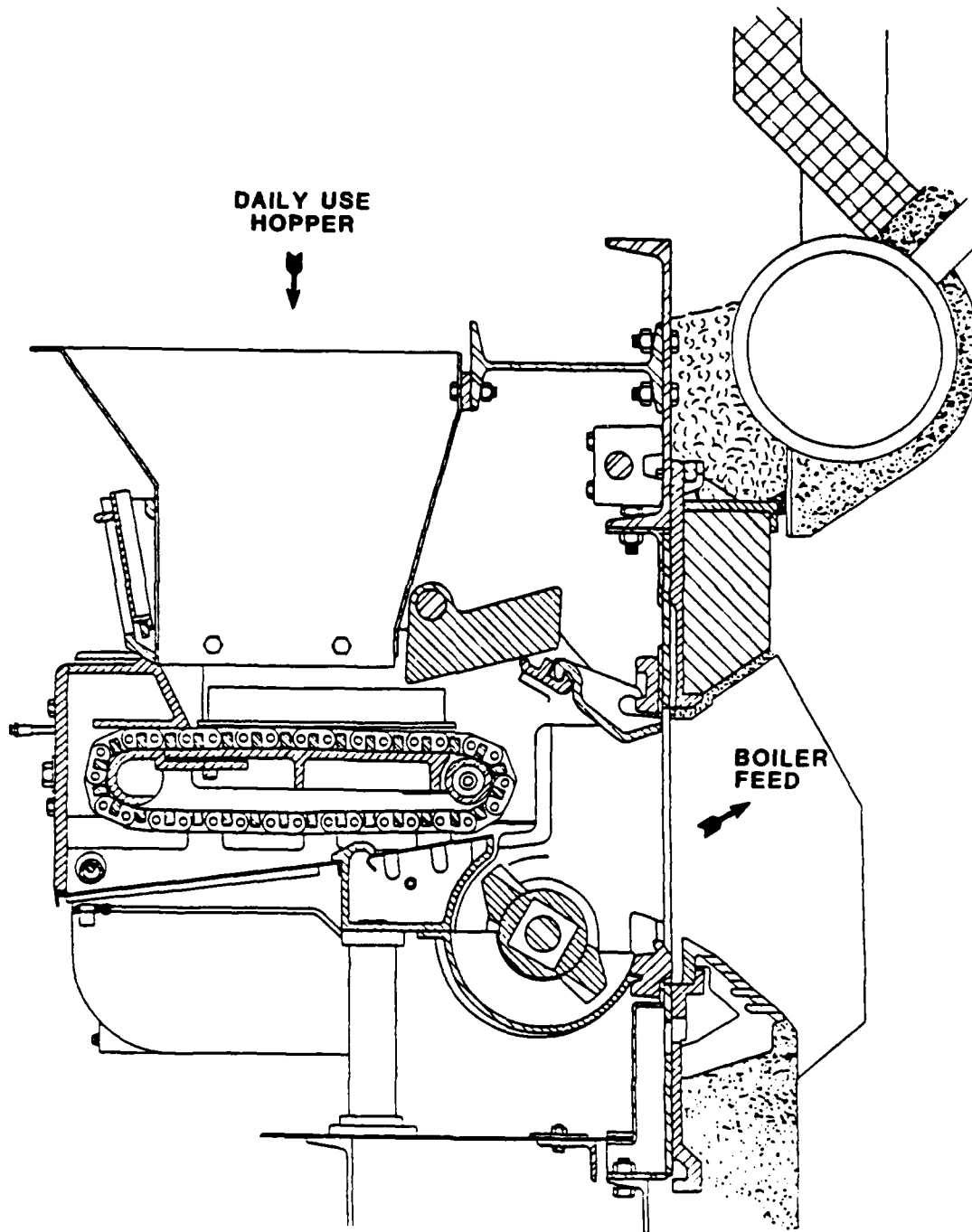


Figure 5-3 Coal Spreader

1. Lean-phase systems are high velocity 4000-6000 ft/min (22-33 m/sec). Dense-phase velocity is 600-1000 ft/min (3.5-5.7 m/sec).
2. Lower velocity allows mild steel Schedule 40 or 80 pipe to be used.
3. Air consumption of a dense-phase system is lower using a standard 80-100 psi (7 bar) supply.

Conventional marine practice is to use a vacuum-pneumatic system, with overboard discharge being carried out by means of hydraulic ejectors. A dry-transfer system is preferable to a wet system because the combined volume of ash and water is considerably lower. Refer to Figure 5-5 [13].

Operators have experienced difficulties with their ash handling systems. The ash content of the coal is slightly higher than originally predicted. It is running 6-8% instead of 5% for U.S. East Coast coal. Australian Callide coal loads have significantly higher ash content (13-23% by weight).

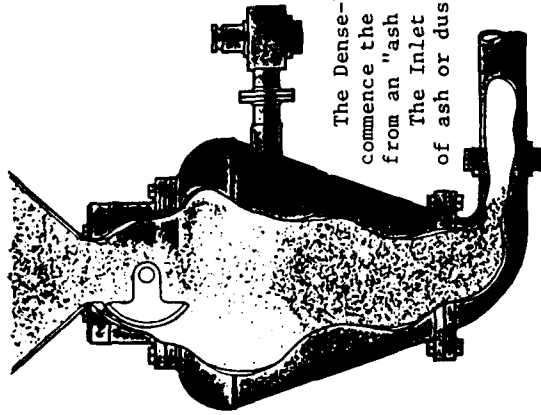
Ash Hopper Capacity. Combined flyash* and bottom-ash hoppers are preferred to separate collection and storage of each type of ash. Although flyash has potential economic value, operators have opted for dumping ash at-sea outside of protected coastal areas due to a much larger volume of ash than was forecasted. Ash hoppers below the boiler(s) must be adequately sized to accommodate at least 24 hours ash capacity while steaming at full power.

One Australian owner indicated that bigger ash storage silo capacity would be desirable. This was due to the unforeseen requirement for moving the ships to alternate trade routes. The ash handling system on his ship has been designed to hold one round trips worth of ash in the ash storage silo. The ash was supposed to have been about 13% of the original coal tonnage by weight, on the average. Variations, however, have been experienced in which up to 16% of the coal weight has been ash. The ash hoppers are lined with Corten steel and an inorganic zinc coating. The owner increased the scantling thickness of the Corten steel by 20%. Their ships have been in service approximately 12 months and no deterioration has been observed. The ship has a considerable number of ash leaks. Non-enclosed swing-check valves are the source of numerous leaks. The design objective was to have an ash free engine room. A screened bulkhead is located between the turbine and boiler rooms. However, the ash leaks from swing-check valves located above the steam turbines are contributing ash and unburned coal dust to the propulsion machinery space below. The general cleanliness of the ship will improve after engineering fixes for the initial ash handling system problems are worked out.

Ash Handling System. In general, erosion rates throughout the ash piping system have been much higher than expected in the design stage. This has required constant maintenance action, monitoring leaks and pipe failures as well as replacing parts. This is due both to abrasive ash and higher than allowed for pipe velocities.

Pipe wear rates in lean-phase systems have been a problem on existing ships. Removable sections of pipe (wearbacks) have been installed to allow the crew a quick change-out procedure for high wear rate sections of piping.

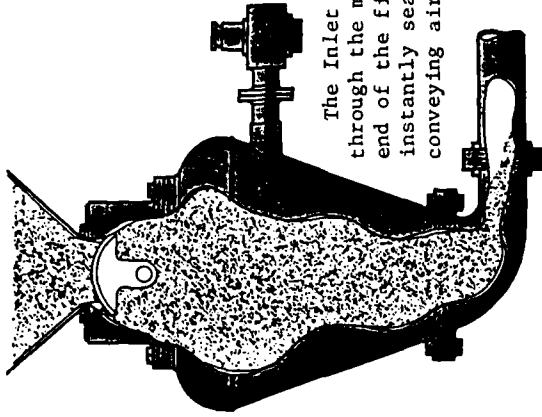
Materials selection in ash handling systems is critical. No mild steel piping can be used. Spin cast, Nihard piping and fittings with replacable wearbacks are required. Bends should be minimized.



STEP 1

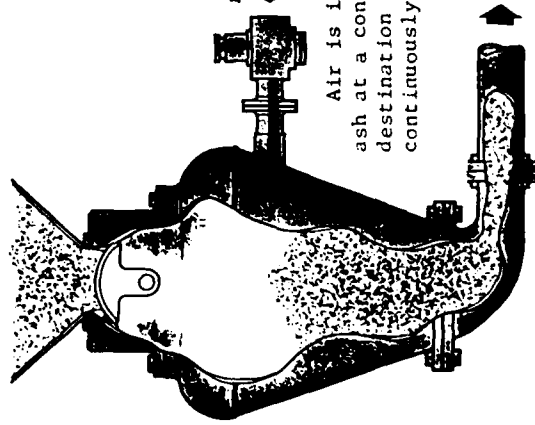
The Dense-Phase unit is signalled to commence the filling part of the cycle from an "ash chute full" signal.

The Inlet Valve opens to accept a supply of ash or dust from the hopper above.



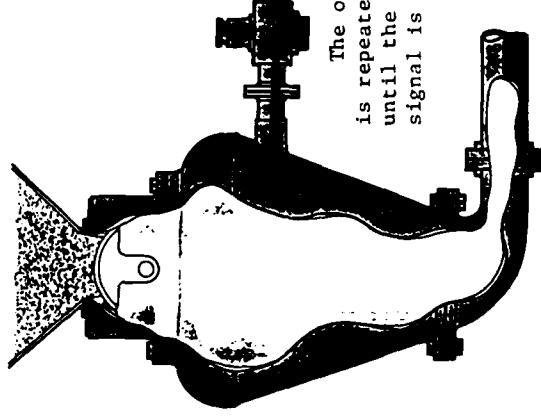
STEP 2

The Inlet Valve closes through the material at the end of the filling sequence and instantly seals to prevent the conveying air escaping.



STEP 3

Air is introduced, to pump the ash at a controlled rate to its destination without the need for continuously fluidizing the material.



STEP 4

The operating cycle is repeated continuously until the "ash chute full" signal is cancelled.

Figure 5-4 Dense Phase Ash Handling System

Gate valves in ash handling systems should be totally enclosed to prevent leakage of dust (soot) particles. Use of enclosed valves noticeably improves the housekeeping within the machinery spaces.

Overboard Ash Discharge

Ash discharge is another unique requirement of coal-fired ships. Due to environmental prohibitions of dumping in port areas and protected coastal zones, it will be necessary to store ash and discharge it at sea in certain ports-of-call. On most trade routes the storage capacity is required only for the longest port turn-around time plus a reasonable margin for delays.

Both vacuum pumps and water ejectors have been in-service with no major problems reported. Steam ejector systems have suffered several problems. There have been two major problems identified with steam ejector discharge nozzles. First, adequate filtration and condensation of steam with carried over ash. Second, steam ejector flowrates have not met design specifications. One installation was designed without adequate filtration and seawater condensation. The result was dirty (black) steam exhausted from the side of the ship. The additional back pressure on the ejector system caused reduced ash discharge pumping rate. A new Nihard supersonic steam ejector nozzle is being refitted to increase the ash discharge rate. Most operators agree that far better experience was achieved with water pump and vacuum ash systems rather than the steam ejector nozzles. Crewmen experienced with lake, coastal and river coal-fired plants have successfully used hydraulic ejector nozzles for many years. These systems use large seawater pumps to drive the ejector nozzle. Good experience has also been reported with vacuum pump systems.

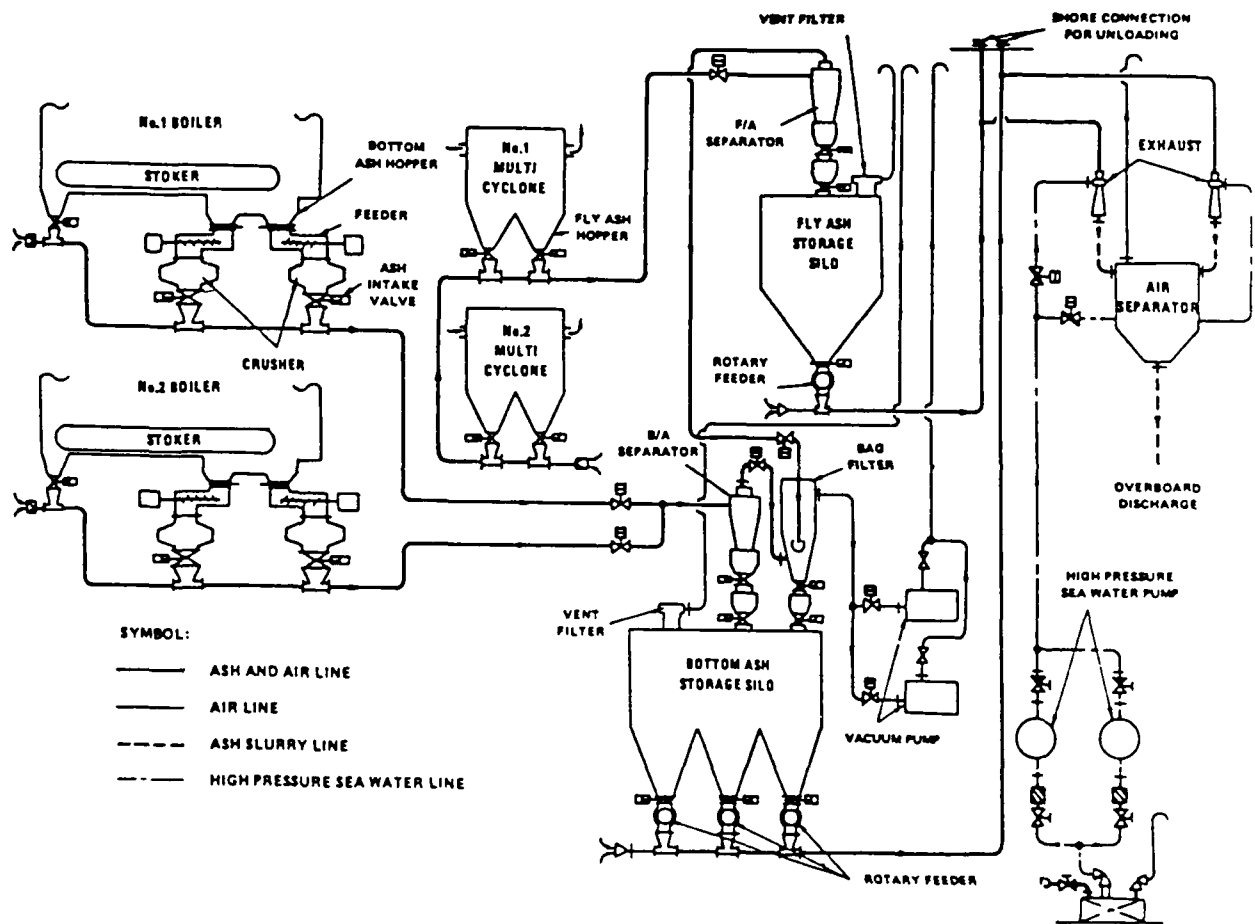


Figure 5-5 Typical Ash Handling System

FUTURE DESIGN CONSIDERATIONS

This chapter summarizes owner and operator opinions and recommendations with respect to future trends in the bulk shipping business. Their responses agree on several major points:

- o Stoker fired marine steam boilers will be standard technology until fluidized bed boilers are developed for marine applications.
- o New generation, coal fired ships will be shallow-draft wide-bodied bulk carriers, incorporating both mechanical and pneumatic coal handling systems.

Fluidized Bed Boilers

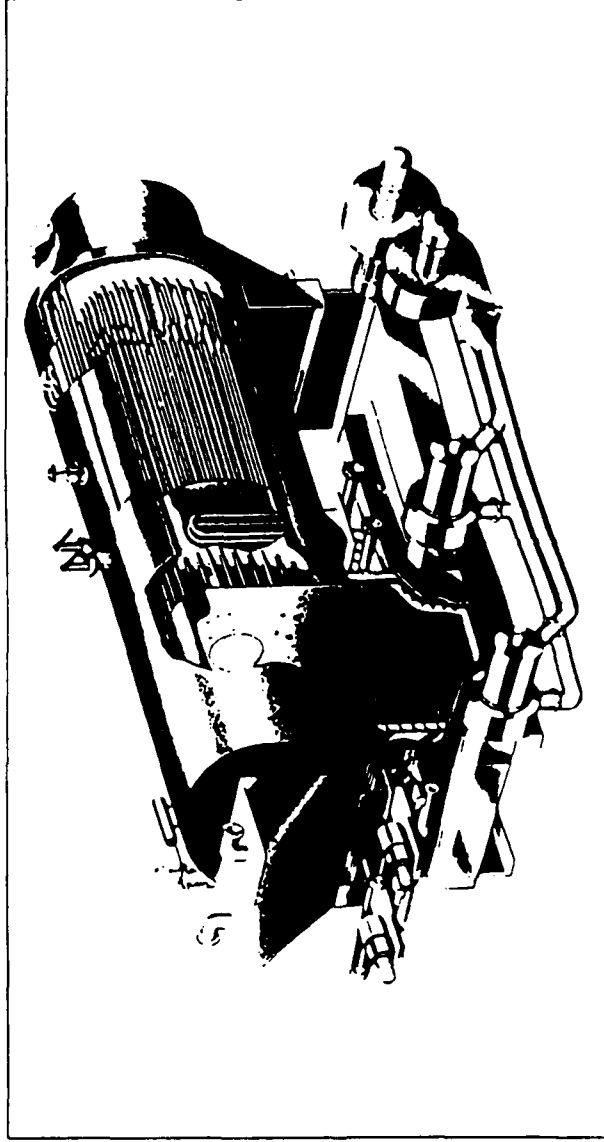
The most common complaint regarding in-service experience of operators and crews of coal-fired propulsion systems is that coal received on-board is "out-of-specification". Most of the current deliveries of steam coal are going to shore-based power plant boilers. It is common practice in these plants to pulverize the coal just prior to firing in the boiler. This makes them relatively insensitive to the physical properties of the coal.

Intense development and marketing activity for fluidized bed boilers in the commercial market, both in the United Kingdom and on the European Continent, has been reported. It has been estimated that as much as 7% of new boiler sales for small land-based systems are fluid beds. Currently the largest commercial bed is about 2 meters x 3 meters in area. A large Belgium-UK consortium produces a standard range of boiler designs which can produce saturated steam, hot water or hot gas. They are advertised simply as having the ability to burn "any hydrocarbon fuel whether solid, liquid or gaseous". The systems use a "two-stage" fluidized bed process. The fluid bed temperature must be controlled to insure that rapid oxidation of the coal occurs without additional heat release into the bed which would result in exceeding the ash fusion temperature of the coal. The latter would result in clinker formation in the bed materials. The solution used is to recycle a percentage of the exhaust combustion gases into the fluid bed. A significant portion of the heat release will occur in the gases above the fluid by supplying secondary air above the bed.

A compact fluidized bed boiler design of the shell and tube type has been proposed for the 5 to 7 MW power equivalent capacity [7]. It is estimated that the boiler design depicted in Figure 6-1 can work at pressures up to 30 bar and at temperatures up to 500 degrees C. Several boilers of that design have been installed at commercial sites. The largest will generate 60,000 lb/hr steam flow at a pressure of 18.7 bar, and steam superheated to 260 degrees C. The boiler diameter is 10 feet (3.048 m) and total length is 39 feet (11.89m).

New Bulk Carrier Design

Presently, four bulk ships, two in the United States and two in Spain, have been converted to coal-fired steam propulsion. The converted ships range in size between 120,000 - 160,000 dwt. Increases in world trade of steam coal



Trans IMarE(TM), Vol. 96, Paper 55

Figure 6-1 Horizontal shell and fire tube boiler

will result in new exports from the United States, South Africa and Australia as mentioned in earlier chapters. The trend will result in additional coal-fired bulk carriers in this size range.

The best example of "new generation" coal carrier designs are two 154,000 dwt ships currently being converted in Spain [6]. The operator has projected a tenfold increase in Spain's imported steam coal from 1.5 million tons in 1980 to 17 million tons in 1986-87. The new coal fired bulk carriers have been designed to "go anywhere". The total cruising range when both cargo holds (main bunker - Hold #6; auxiliary bunker - Hold #4) is about 27,000 nautical miles. The basis for this route is possible trade between Gladstone, Australia and Northern Europe (Rotterdam). The first ship has been chartered for operation between Richards Bay, South Africa near Durban and Northern Europe. This voyage only requires use of the main cargo Hold #6 as the fuel bunker. Total bunker capacity is near 25,000 n.m. broken down as follows:

Hold #6 Main Bunker	11400 n.m.
Hold #4 Aux. Bunker	13600 n.m.

Location of bunkers was determined by hull bending stress considerations and the need to be near level trim in shallow water ports.

Cargo holds are used for bunkering coal both because of the volume needed for this extended range trading and the fact that the trim of the vessels must be kept near level for both cargo loading and topping off operations as well as transit in limited draft channels. Potential ports of call in the United States (with limited draft) include Hampton Roads, Virginia, midstream in the Mississippi River, Galveston Bay and Mobile, Alabama.

The ships are "wide-bodied" limited draft tanker hulls with a length/beam ratio of 5.62. This allows the ships to comply with both length and draft restrictions imposed by many terminals. The principal characteristics are as follows:

LBP	259 meters
Beam	46 meters
Draft (full)	11 meters
Maximum ballast	8000 tons
Bunker capacity	25000 m
Trial speed	15.5 kts
Contract speed	14.5 kts
SHP	23000
Propeller speed	85 rpm

Coal Handling Equipment. The coal transfer system includes special detectors for sensing a blockage and releasing additional air into the transfer line. Mild steel piping is used for the coal transfer system. A coal (fuel) handling equipment room has been located at the bottom of the main bunker, Hold #6 (Refer to Figure 6-2) [14]. The hold is separated into two compartments by an athwartships bulkhead. This feature allows carrying two types of coal and keeping them separated or mixing them by scheduling the dense phase unit control system to alternately select coal from each half of the bunker. A 25 meter high machinery compartment is located beneath the transverse bulkhead separating the two halves of the cargo hold. Within this machinery space the following equipment is located:

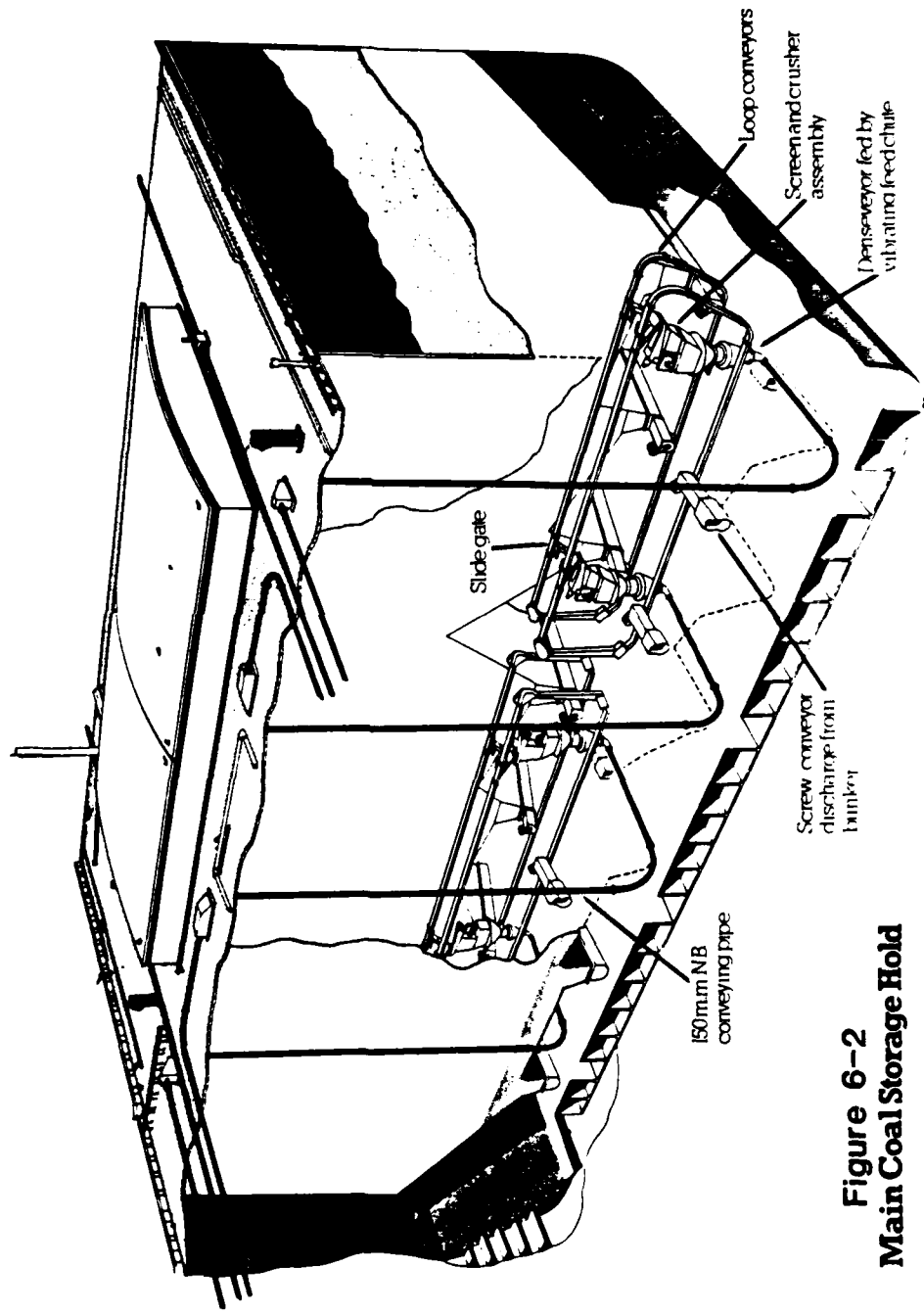


Figure 6-2
Main Coal Storage Hold

Coal Hopper Silo Walls - 12 bins
Screw Feeders - 12 fore/aft
Mechanical Conveyor Lifting Loop - 2
Coal Screening and Crushers - 4
Dense Phase Transfer Units - 4
Air Receivers - 2
Control Air Receivers - 2

The sloped surfaces of the cargo holds are lined with 304 stainless steel for reduced friction and abrasion resistance. The mass flow design of the coal transfer system was done by the consulting firm of Jenike & Johansson. They also designed variable pitch feeders which transfer coal from the bottom of each bunker to the mechanical chain link lift system.

Machinery for transporting coal located in the #6 Hold is very accessible for maintenance and repair. The space will have CO monitors as well as adequate forced ventilation, grates and ladder access to all machinery. Air pressure sensors and injectors will be automatically located every (2) meters. Distilled water lines with manual valves will be located above each dense phase unit for flushing out blockages within the unit.

The coal handling equipment located in the forward (#4) hold is considerably less accessible (Refer to Figure 6-3) [14]. The hold will normally be used for cargo on all but the longest trades (Australia to Europe and returns). Thus it has no transverse bulkhead separating it into two compartments. Rotary screw feeders located at each corner of the cargo hold move the coal towards the center of the hold. A second, shorter transverse rotary screw feeder then feeds the coal onto a mechanical conveyor lift system similar to the ones used in the main bunker hold. One dense phase unit is located at the aft end of the Hold #4 on both the port and starboard sides. They are equipped identically to the four units located in Hold #6 with screening and crushers. The screen opening is 1-1/2 inch mesh (36mm).

Provisions have been made for transfer of coal from Hold #4 to the forward half of Hold #6 (main bunker) or directly to the ready to use hoppers. Due to the fact that a complete screw compressor can be independently devoted to this transfer operation, it can be run in parallel with full power operations and all coal transferred directly from one of the four dense phase units in Hold #6 simultaneously. Only one of the six units supplying 12 tons/hr of coal can keep the plant at full steaming capacity. There is, thus, considerable redundancy in the design.

Other options for mechanical transferring systems have been proposed, but not yet put into service. Another example of a combined mechanical and pneumatic dense-phase system is shown on Figure 6-4[14]. In this design mechanical cross conveyors are used to move the coal athwartships into a loop conveyor. The mechanical loop conveyor then feeds into a dense-phase transfer unit.

A new barge self-unloading system design, not yet installed in a ship, has been developed (Refer to Figure 6-5) [15]. The system uses a mechanical conveyor belt located on the centerline of the vessel to transfer the coal forward to a retractable telescopic discharge conveyor assembly.

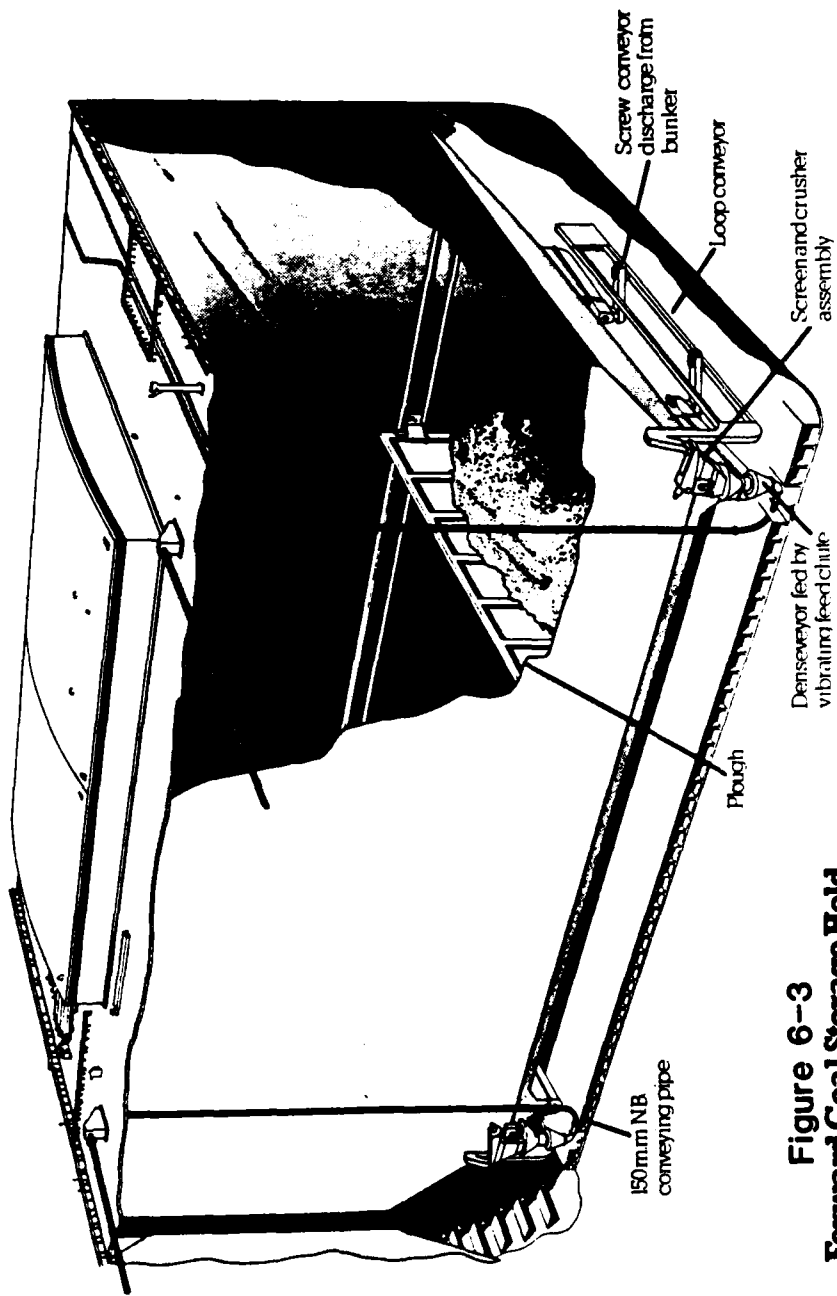


Figure 6-3
Forward Coal Storage Hold

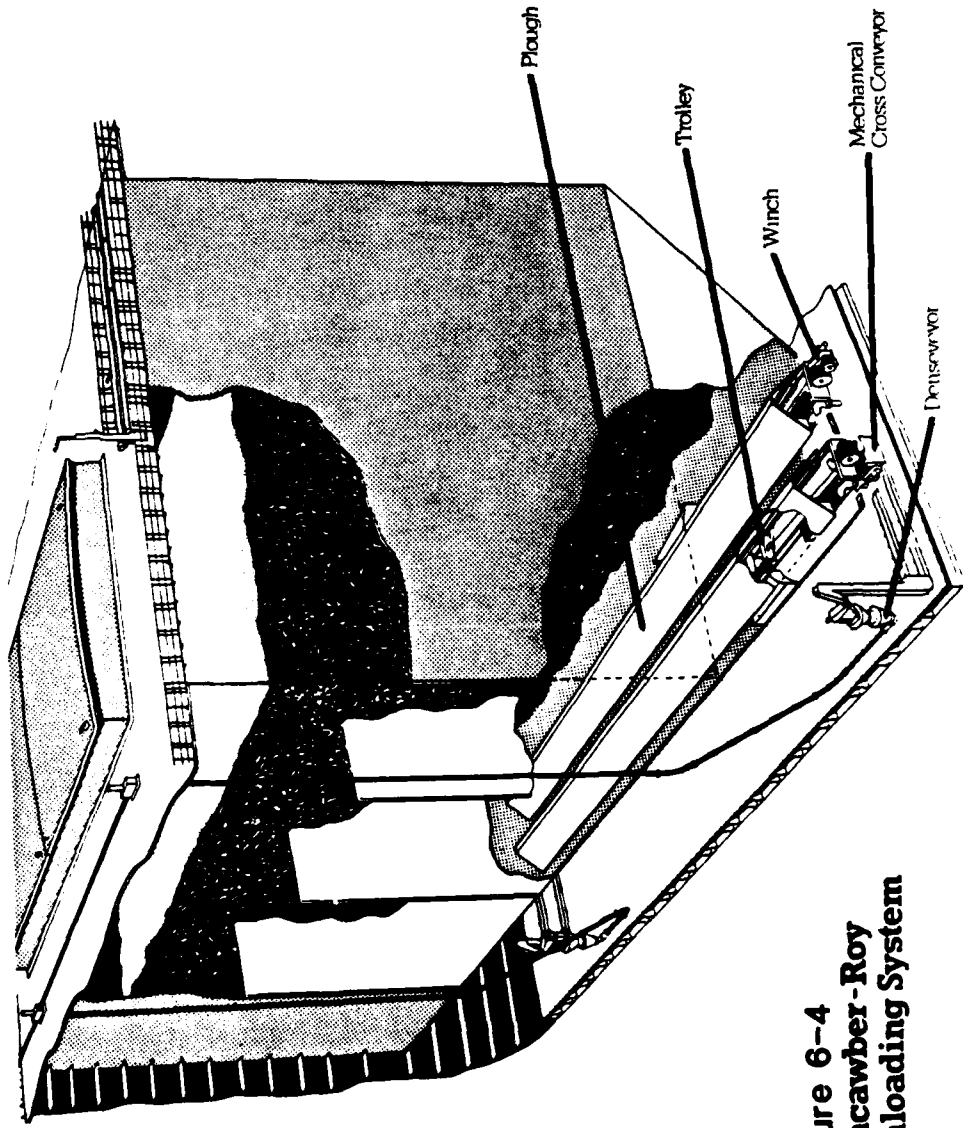
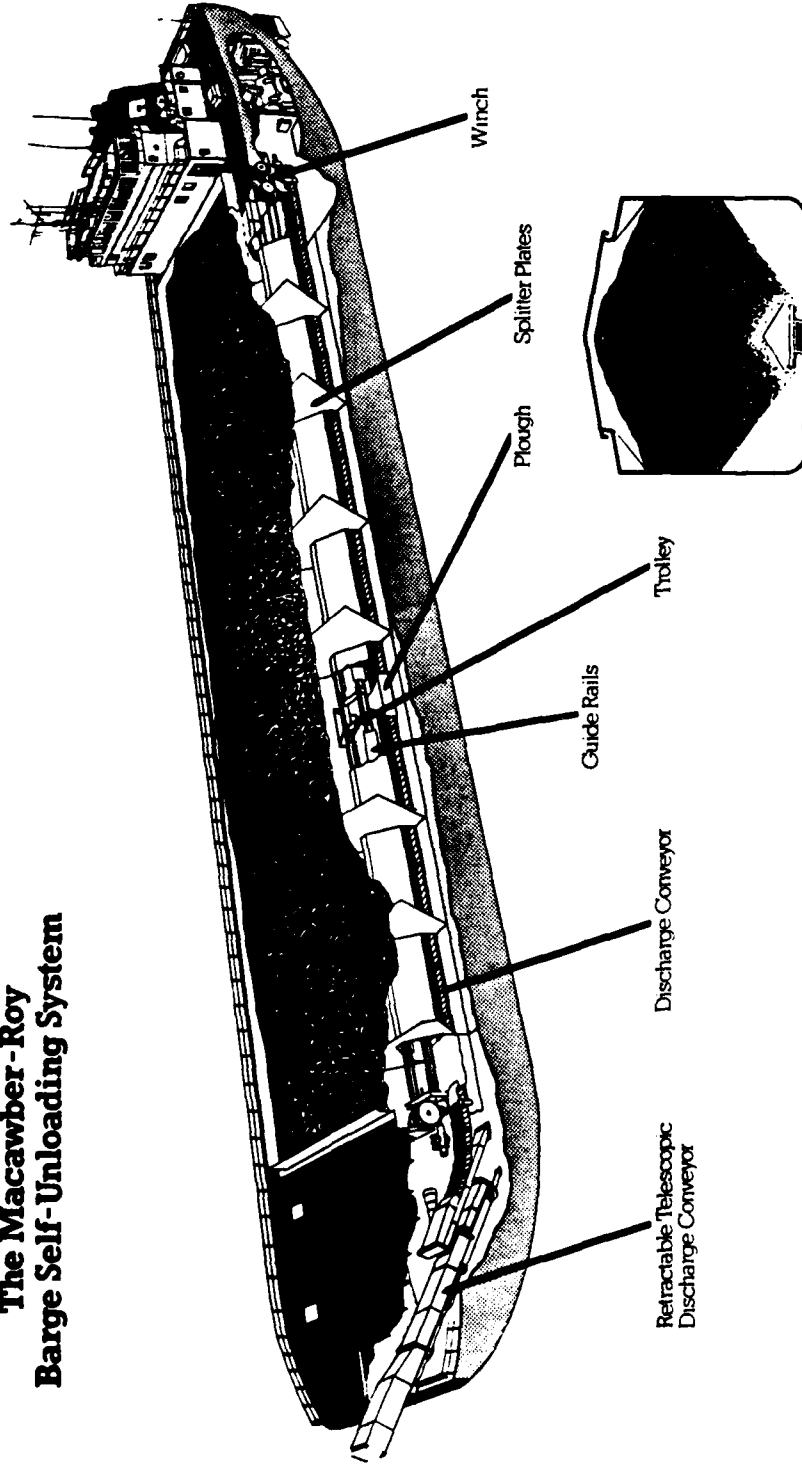


Figure 6-4
The Macawber-Roy
Bunker Unloading System

Figure 6-5
The Macawber - Roy
Barge Self-Unloading System



Ash Handling System. Ash enters the disposal system in a conventional manner, through the siftings hopper below the grates, the dust collector hoppers, the boiler hoppers, or the bottom ash hopper. The bottom ash hopper employs a clinker grinder to decrease the particle sizes entering the conveying system.

The vacuum/pneumatic system draws the ash up from various hoppers. The branch lines join into a main line which conveys the ash overboard or into a storage silo. The silo will be required during operation of the boilers in port. The ash will be subsequently discharged at-sea. The required vacuum is provided by three salt water eductors. The eductors are served by three pumps in parallel; two of which are part of the firemain system.

Separate ash storage silos for flyash and bottom ash storage are provided. The silos are 2472 ft (70 cubic meters) each. Based upon Australian experience, this arrangement may impose undesirable restrictions in certain ports. The ratio of flyash to bottom ash will not be uniform, rather, will vary with the source of coal. Combined ash storage eliminates this difficulty. Also prolonged operations in protected coastal zones such as the Great Barrier Reef and Chesapeake Bay may require greater storage capacity for the silos.

Dust Collectors. Mechanical cyclone dust collectors are located in the gas stream between the economizer and induced draft fans. This type of separator has failed to reduce stack gas opacity to low enough levels in one existing ship. The major difference in the latter case was that the dust collector was located upstream of the economizer and one less hopper was provided for re-injection of cinders in the previous design. Perhaps the location will improve the overall collection efficiency of this new design. By contrast, excellent results have been obtained in-service with multi-stage cyclone systems in Australia. These should be used with secondary centrifugal separators and bag filters to assure adequate particulate removal.

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APPENDIX A
LIST OF CONTRIBUTORS

SHIP OWNERS

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Mr. Colin Burke
Manager, Fleet Technical Operations

TNT Bulkships Ltd.; New South Wales, Victoria, Australia
Mr. Graham Taylor
Group Technical Manager

ELCANO; Madrid, Spain
Mr. J. Bouthellier
Director, Project Development

SHIPYARDS

BAZAN; El Ferrol, Spain
Italcantieri; Monfalcone, Italy

CLASSIFICATION SOCIETIES

Lloyds Register; London, England

EQUIPMENT MANUFACTURERS

Foster-Wheeler; London, England
Macawber Engineering Ltd, Doncaster, England

APPENDIX B

DEFINITIONS

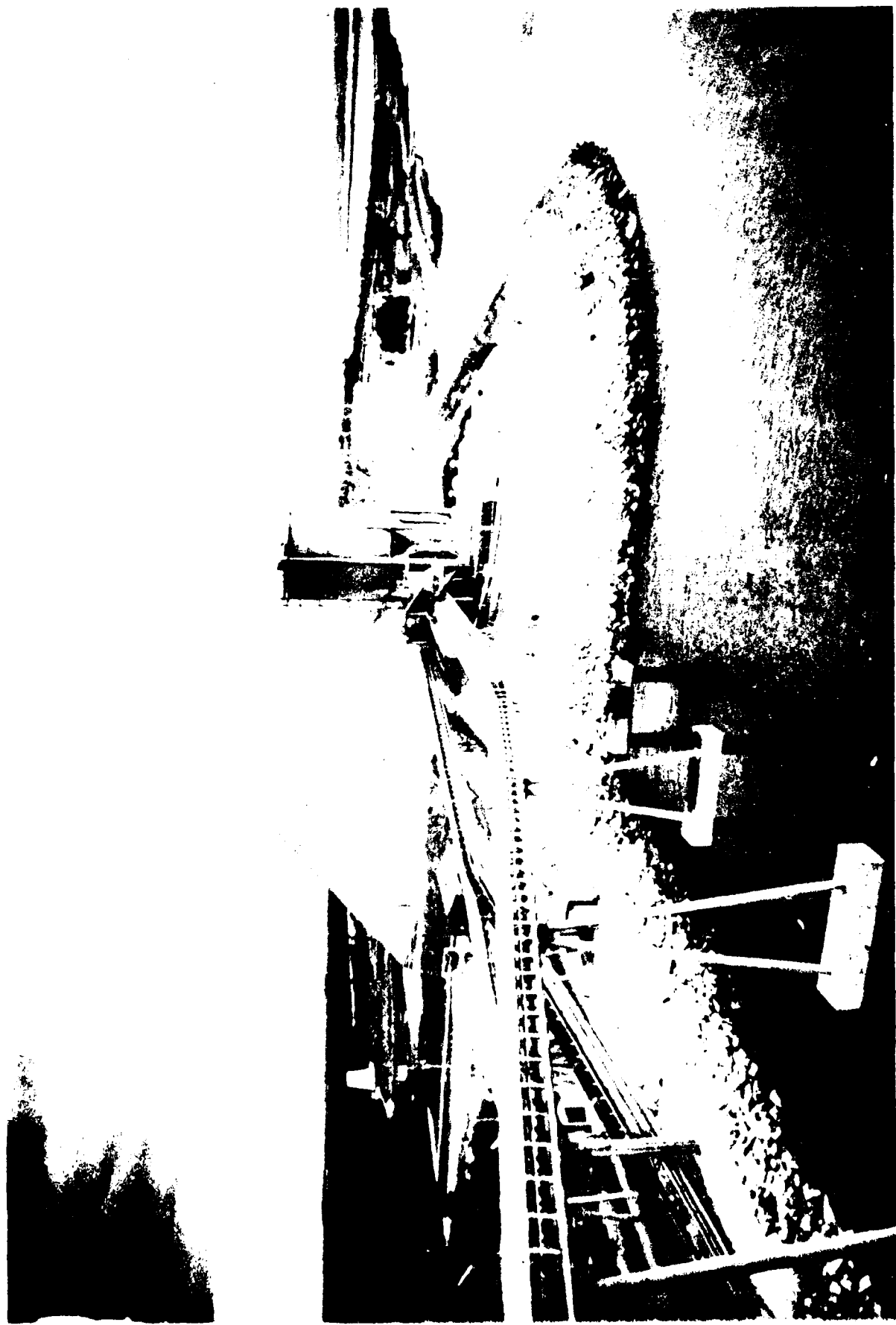
- Clinkers - Lumps of coal and ash fused together during the combustion process.
- Coal Ignition - When heated to about 100 degrees F, coal may be spontaneously ignited without the help of any external flame.
- Densenveyor - Trade name for pneumatic conveying systems manufactured by Macawber Engineering Ltd, U.K. The company has manufacturing facilities in the U.S. and Australia. Standard Densenveyor systems are designed to accept coal lump sizes of up to 3 inches in diameter. It has the ability to transfer coal at low velocities without substantial interangular activity.
- Fines - Coal pulverized to extent that complete combustion is not possible in the combustion chamber of the boiler. Coal suitable for boilers or Specification Coal is an even mixture of coal nuggets and fines. 50 to 60 percent by volume of fines in coal is the maximum acceptable limit for marine boilers.
- Flyash - The ash which finds its way up to the superheater and eventually to the stack instead of the ash bed on the grate. The unburnt coal particulars from the flyash are re-injected into the furnace.
- Hot Spot - The location of local hot areas in the coal storage holds, which might be the result of a coal fire within the storage hold of an external heat source which may eventually lead to a spontaneous ignition of coal.
- Peaks and Troughs in Coal Bunker - When coal is bunkered into the coal storage hold, peaks and/or troughs are formed. They are flattened by trimmers to dislodge any entrapped air and to minimize chance of the cargo shifting.
- Segregation - Refers to the segregation of coal nuggets and pulverized coal. It generally occurs during loading operations, in holding tanks or in the transfer systems prior to entry into the boiler. Lowering the air pressure of the pneumatic transfer system can solve this problem partially. Segregated coal feed causes unstable evaporation in the boiler.
- Slicers - Instrument to break up clinkers into coal nuggets.
- Tramp Iron - Abrasive ferrous material which may be carried along with the coal during its passage from the coal mine to the ship.

APPENDIX C

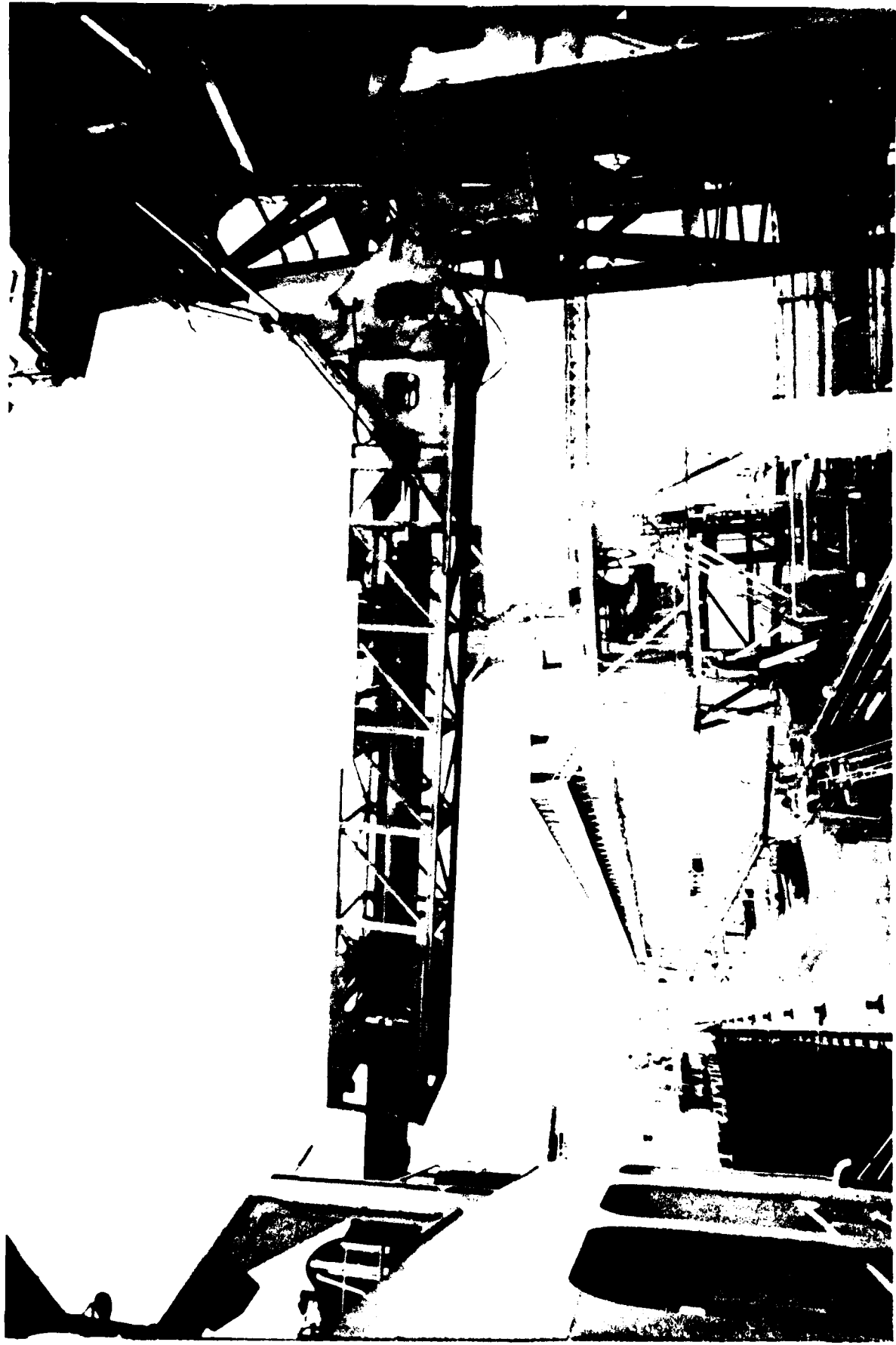
PHOTOGRAPHS

AUSTRALIAN
BAUXITE CARRIER
DUAL BOILER STACKS

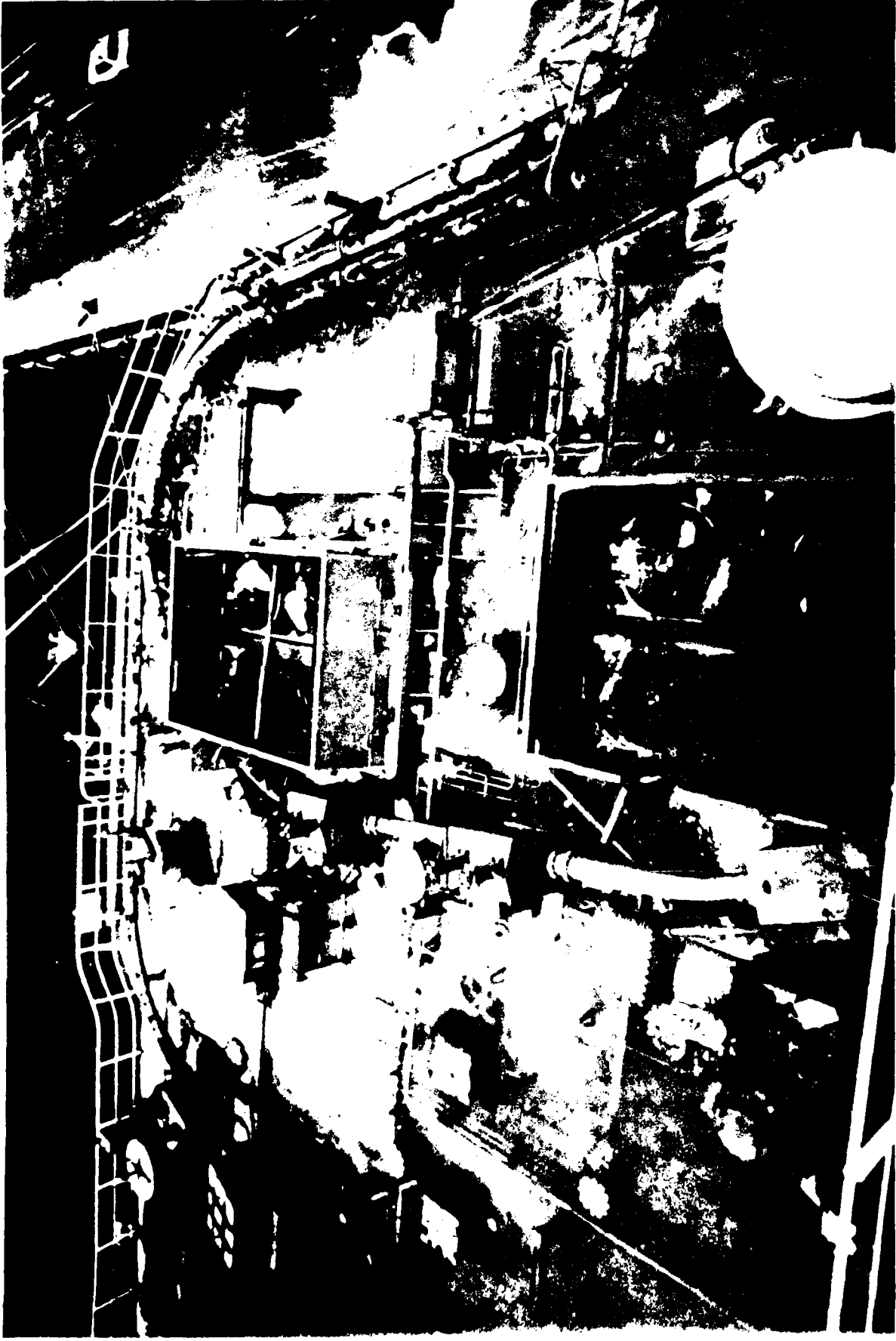




AUSTRALIAN COAL-FIRED SHIP BUNKERING FACILITY
WITH 2000 TON STORAGE TANK



AUSTRALIAN COAL-FIRED SHIP
LOADING ASSEMBLY

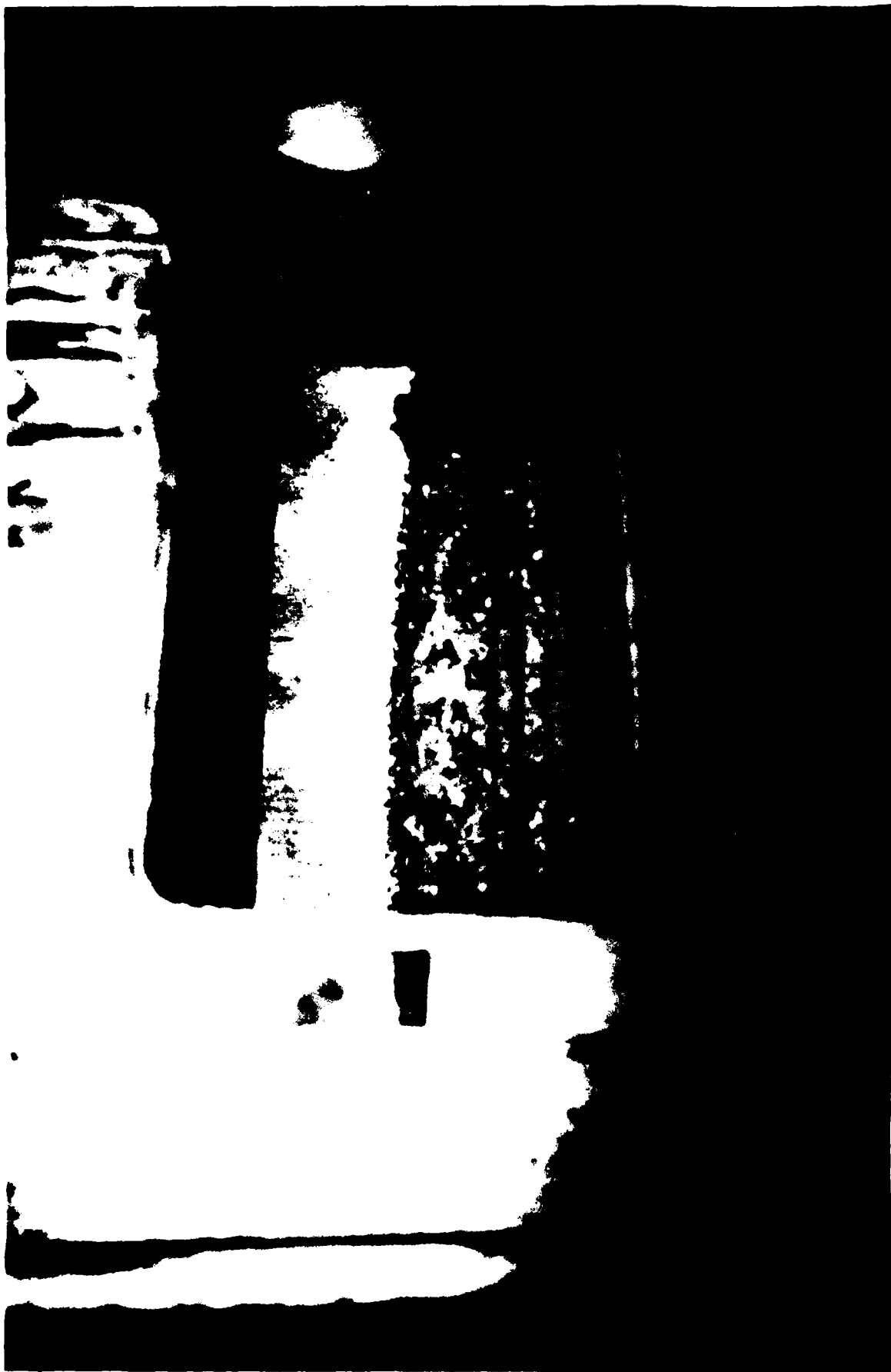


AUSTRALIAN BAUXITE CARRIER
COAL BUNKER LOADING ARRANGEMENTS





COAL STORAGE HOPPERS AND PNEUMATIC TRANSFER PIPING



**COAL-FIRED BOILER GRATE AND
ASH BED IN OPERATION**

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