THE PETROLEUM HANDBOOK

ELSEVIER

these functions is much the same at both; installations, however, operate on a much larger scale than depots, and consequently the size and range of their facilities are generally greater. Moreover, individual installations and depots vary greatly in size and scope; some handle only "white" products, some only "black" products, some both. Again, some handle products only in bulk, others partly in bulk and partly packed, while depots may handle only packed products. The actual plant and equipment required in any particular case are determined by the range of products handled, the volume of the trade and the nature of the operations carried out.

Both installations and depots require amenities for staff and labour, ranging from the usual washrooms, canteens, etc., customary in any factory, to living quarters and services for a complete community in an isolated location.

The organisation of an installation must be such as to ensure that the demands of the market are promptly and efficiently met, stocks of products are maintained at an adequate but not excessive level, the quality of products is up to specification, losses are eliminated as far as possible, plant and equipment are maintained in good condition, safety measures are observed and costs kept as low as possible.

The manager of an installation is in contact not only with his own staff and the local branch office of his company but also with labour unions and staff associations, the officers of tankers, the officials of transport organisations, contractors, and numerous local authorities such as police, fire, public health, factory inspectorate, customs, weights and measures, harbour board, etc. In addition he often becomes virtually the unofficial mayor of the installation community. The duties of the superintendent of a depot are similar, though of course on a smaller scale.

Discharging Facilities

Where installations or depots receive their bulk supplies of products by tanker or barge, the cargoes are discharged through one or more pipelines leading to the manifold or hose exchange. If the vessels can come alongside there is nothing unusual about these pipelines, but if the vessels have to moor offshore it is necessary to provide either a submarine pipeline from shore to the mooring point or a floating pipeline that can be launched and towed into position when required. The connexion between a vessel and the pipeline is made by means of flexible hoses.

Tanker discharge lines are usually fairly long and have to be reasonably large (with capacities up to 2000 tons/hour) to reduce discharge time and to speed tanker turn-round. It would therefore be very expensive to provide a separate line for each product and generally only two lines are required, for black and white products respectively. Segregation of individual white oils is usually ensured by pumping water between successive grades. This causes no difficulty as the water rapidly settles to the bottom of the shore tank and is periodically drawn off. Black oils cannot be handled in this way as they form fairly stable emulsions with water. They are therefore generally pumped between products and the small amount of down-grading due to mixing at the interface is accepted. Whenever possible, tanker discharge lines are left full of product; otherwise, white oil lines are cleared with water and black oil lines with compressed air.

Some products, such as bitumen and LPG, require special handling and have their own separate discharge lines. Other products, such as lubricating oils, need special care to prevent contamination and may require separate lines, either one for each grade or one for each group of compatible grades. Lubricating oil lines are always cleared with compressed air and never with water.

When installations or depots are supplied by road or rail the discharge lines are generally short and fairly small and segregation is ensured by providing a separate line for each product.

Pumps

Pumps are used for all movements of oil through installations and depots. Reciprocating, duplex, double-acting pumps (pumps with two cylinders and using both sides of the piston), were at one time the most widely used, but are being replaced to an increasing extent by centrifugal pumps, which have the advantage of a smooth instead of a pulsating flow, together with simple installation and control. For heavy products, however, rotary, positive-displacement pumps, which have a very fine clearance between impeller and casing, are used and can efficiently handle liquids with viscosities up to about 3,500 sec Redwood I (4,000 SSU, 113° Engler) at pumping temperature. With products of still higher viscosity it is generally more economic to reduce viscosity by heating than to use more powerful pumps.

The capacity of each pump depends on the service required; for filling packages it depends on the capacity of the filling machine; for filling bulk lorries and rail tank wagons a filling rate of about 15 minutes per vehicle is generally aimed at. The individual pumps are usually capable of dealing with two filling points at a time; when larger throughputs are required two or more pumps are used in parallel. Pumps are often operated by remote control and when two or more are used in parallel they may be arranged to start or shut down automatically in sequence according to the demand at the filling points. For filling barges and small coastal tankers, and for bunkering, pumping rates up to 500 tons/hour or more may be needed. Bunkering pumps are generally controlled by an operator, who receives instructions by telephone from the bunkering point, but remote and automatic controls are also used to an increasing extent.

Chapter 7

TRANSPORTATION — MARINE AND PIPELINES

MARINE

History and Development

When the economic history of the twentieth century comes to be written, the amazing developments in the transport of oil by sea will form an interesting chapter. The first seventy years saw spectacular technological development and almost equally spectacular growth, followed by sudden and sharp decline. A brief survey of developments up to the present day will give some indication of the revolutionary changes which have challenged the tanker industry.

When oil first entered into international trade over one hundred years ago its transport by sea was, like that of most other cargoes, effected in specially made containers. At first wooden barrels were used, but these were subsequently replaced by large iron tanks fitted into the hull of the ship. As the economies of bulk transport became evident, the idea was conceived of using the hull of the vessel itself as the oil container. This necessitated the use of iron ships, instead of the wooden vessels previously employed, and constituted the main principle in the development of the tanker as we know it today. Probably the first ocean-going vessel constructed on these lines was the s.s. Glückauf built in 1885, with a gross tonnage * of 2,307 tons.

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* References are made in this chapter to gross and deadweight tonnages. Gross tonnage, broadly speaking, represents the total capacity of all enclosed spaces in the ship, measured in "tons" of 100 ft^3. Deadweight tonnage (dwt.) represents the weight of the cargo, stores, bunkers and water which the ship can lift, expressed in metric tonnes. It is customary when referring to merchant shipping generally to express tonnage figures in terms of gross tons, but statistics relating only to tankers are more often quoted in deadweight tonnes, which is the measurement used in this chapter except where otherwise stated. With a normal tanker of average size, the gross tonnage is usually about two-thirds of the deadweight tonnage. Reference is also made to the knot, which is a speed of 1 nautical mile per hour (or 1.1515 miles per hour or 1.8532 kilometres per hour).

The use of steam machinery and coal-fired boilers in a vessel engaged in oil transport was still in its infancy and was attended by grave risks in view of the highly inflammable nature of the cargo; but such risks are the lot of the pioneer, and subsequent experience showed that running them was well worth-while.

The next landmark was the passage of the Suez Canal by a fully laden tanker, the first Shell tanker, the s.s. Murex of 5,010 dwt., built in 1892 at West Hartlepool. After lengthy negotiations with the Canal authorities she undertook her maiden voyage from Batum on the Black Sea to the Far East. The passage through the Suez Canal was completed without incident, despite fears that she might prove a danger to other shipping using the Canal. A sister-ship, the s.s. Conch, is shown in Figure 7.1.

From this small beginning some ninety years ago, the average quantity of oil moving through the Canal continually increased and reached 15 million tonnes per month in early 1967. It is interesting to note how one single geographical feature, the availability of the Suez Canal for the transit of Middle East crudes to North West Europe, had a remarkable impact on the development of the tanker industry in the 1950s and the first half of the 1960s.

In the early years of the present century the pattern of the oil trade underwent an important change with the opening up of the Sumatra and Borneo oilfields. Whereas previously oil was carried only from west to east and dry cargo on the return voyage, the new requirement for oil movements from the East Indies to

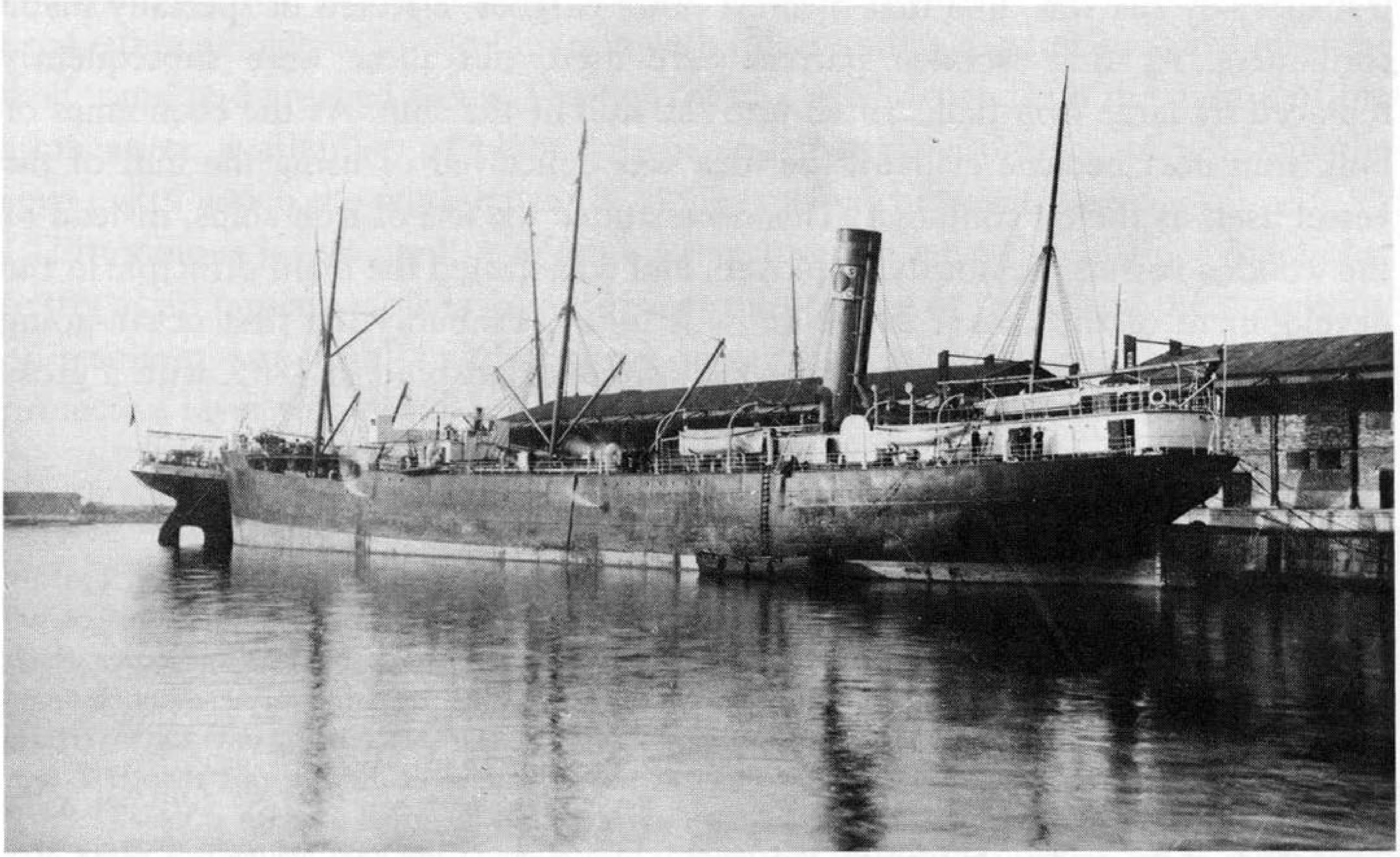

Figure 7.1 **s.s. *Conch;* 5,010 dwt; built 1892. A sister-ship of the first tanker through the Suez Canal.**

Europe made it possible to employ vessels exclusively for the carriage of petroleum. This resulted in a change of tanker design and encouraged some increase in size. At the beginning of the century the total tanker tonnage was half a million tonnes, with an average of 5,000 dwt. per tanker; by 1914 the total tonnage had increased to 2 million dwt., with an average of something over 6,000 tonnes per tanker.

During this period preceding World War I a further development, in which the Royal Dutch/Shell Group played an important part, was the construction of the first ocean-going motor vessel of any kind, the Shell tanker Vulcanus, built in 1910. Although only a small vessel of 1,215 dwt., she amply proved the advantages of motor propulsion and was the forerunner of a large number of motor tankers which today represent 64 per cent of the vessels in the world tanker fleet (39 per cent of the dwt.).

The years between the wars were characterised by a policy of consolidation and gradual development in size, speed and technical improvements. The size of the standard tanker rose to 12,000 dwt. with a speed of 11 knots. Half-hearted attempts were made to push the maximum size up to more than 20,000 dwt. but few vessels of this size were built. By 1939 the world tanker fleet had grown to more than 1,500 vessels totalling $16\frac{1}{2}$ million dwt., of which over $1\frac{1}{2}$ million dwt. were owned by Shell Group companies.

The vital need for oil during World War II gave a tremendous impetus to tanker building. The lead was taken by the USA, which, having developed a standard tanker of 16,600 dwt. with a speed of $14\frac{1}{2}$ knots, proceeded to turn out such vessels in large numbers. During the years 1942 to 1945 nearly five hundred of these ships, known as T2s, were built. Thus, despite heavy war losses, the world tanker fleet by the end of the war had risen to a total of 24 million dwt..

Thereafter began one of the most spectacular advances of shipping history. A number of influences were at work. The growth of the Middle East as a producing centre, the new policy of building refineries in the consuming areas instead of near the oilfields, the enormously increased demand for oil in the industrialised regions and the growing realisation of the economies to be secured from the use of larger vessels, all combined to establish a revolution in outlook. Gradually at first, and then at a quickened tempo, tanker owners began to build bigger ships. From 24,000 dwt. claims were made for the world's largest tanker by successive stages until 132,000 dwt. was reached by 1966, and the world tanker fleet totalled 97 million dwt..

The next seven years can perhaps now be regarded as the greatest period of expansion within the oil industry and consequently in the tanker trades. Output of the world's shipyards increased by leaps and bounds, from some 10 million dwt. in 1966 to over 28 million dwt. by 1973. At the end of that year the largest tanker in service was 476,000 dwt. and total tanker tonnage amounted to some

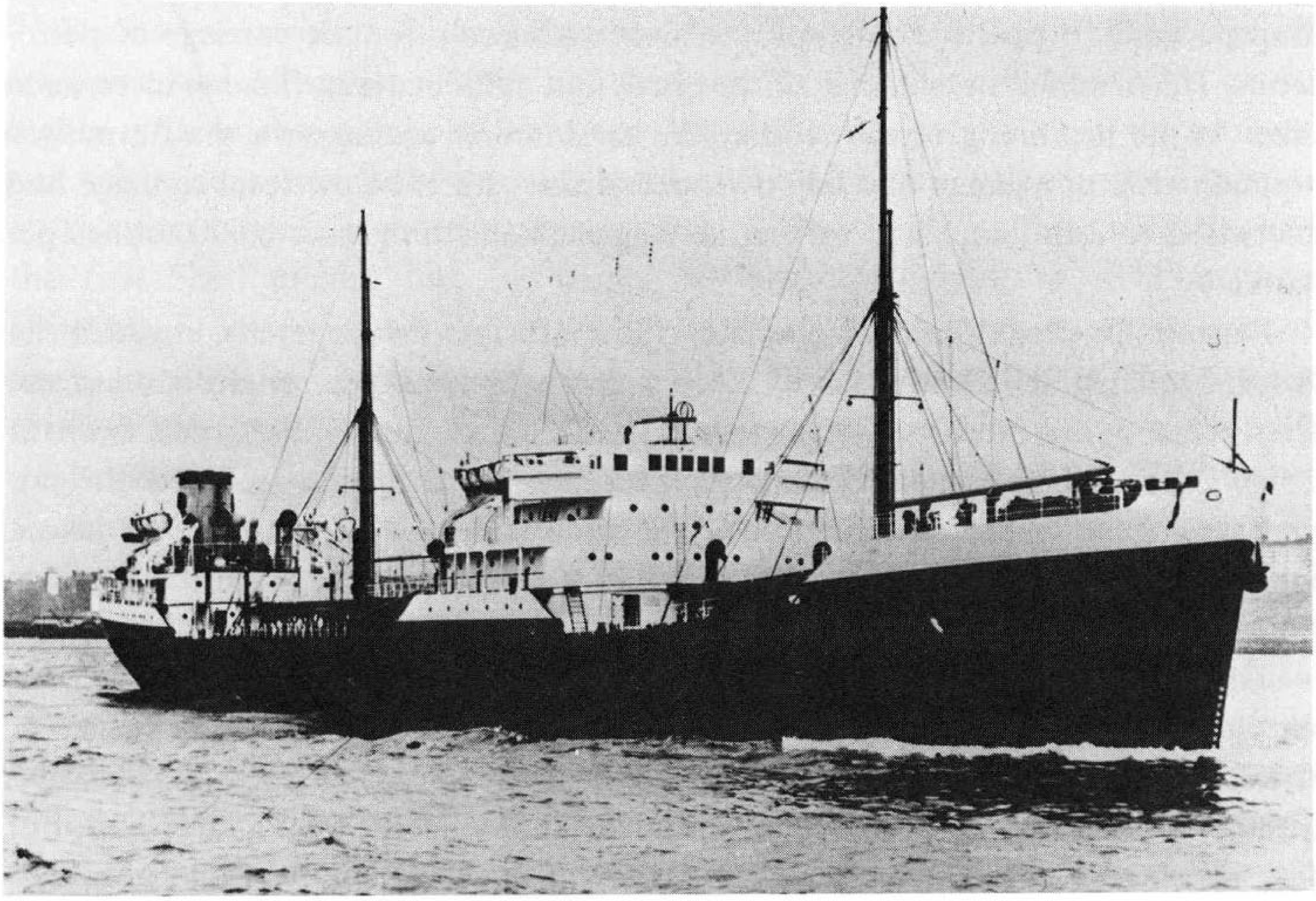

Figure 7.2 **m.s. *Auricula*; 12,248 dwt; built 1946. A typical tanker of the late 1940s.**

Figure 7.3 **s.s. *Leda*; 276, 860 dwt; built 1973. An example of a VLCC, developed in response to the closure of the Suez Canal.**

219 million dwt.. This figure did not include a new sector of the shipping world, namely the combination carriers, i.e. vessels capable of carrying either oil or dry bulk cargoes, of which some 37 million dwt. existed in 1973.

This period of expansion was not free from difficulties. The underlying situation of confrontation throughout the period between Israel and the Arab States and more specifically the physical closure of the Suez Canal from October 1956 to March 1957, and subsequently from June 1967 to mid-1975, had a profound effect on tanker design, planning and operations. Compelled to sail both laden and ballast via the long route around the Cape of Good Hope, the shipping and shipbuilding industries reacted swiftly to the need for additional capacity. Being free from the draft limitations of the Suez Canal the Very Large Crude Carrier (VLCC) was born, initially of about 200,000 dwt. but subsequently much larger.

The speed of the reaction to the challenge is illustrated by the fact that in mid-1966 there was one tanker of over 150,000 dwt.; by mid-1973 there were 351. The growing importance of the larger ships is shown in Table 7.1.

Table 7.1 **World Tanker Fleet (2,000 dwt. and over)**. Percentage of Total Carrying Capacity

	Up to 25,000 dwt.	25,000 to 45,000 dwt.	45,000 to 80,000 dwt.	80,000 to 160,000 dwt.	Over 160,000 dwt.
1951	93	7	–	–	–
1961	50	37	11	2	–
1971	15	15	22	22	26
1981	4	8	11	19	58

In economic terms, the importance of the larger vessel is reflected in lower transportation costs as illustrated in Figure 7.4. This graph is based simply on newbuilding capital costs and owners' and charterers' operating costs; it does not take into account the effects of market conditions, which may yield the owner a return not commensurate with his capital investment, or of scheduling problems, which may result in inefficient trading patterns such as the need to call at many ports on a voyage in order to handle the volume of cargo carried. Problems such as the latter tend to provide a natural inhibition to progressing to even larger vessels.

By 1973 the largest size category already included a few ships over 350,000 dwt. and plans were being drawn up for ships of 500,000 dwt.. The era of the mammoth tanker had indeed arrived. This dramatic increase in ship size was not, however, matched in the earlier years by equivalent expansion of the shore facilities to accept these ships, particularly in the West European discharging

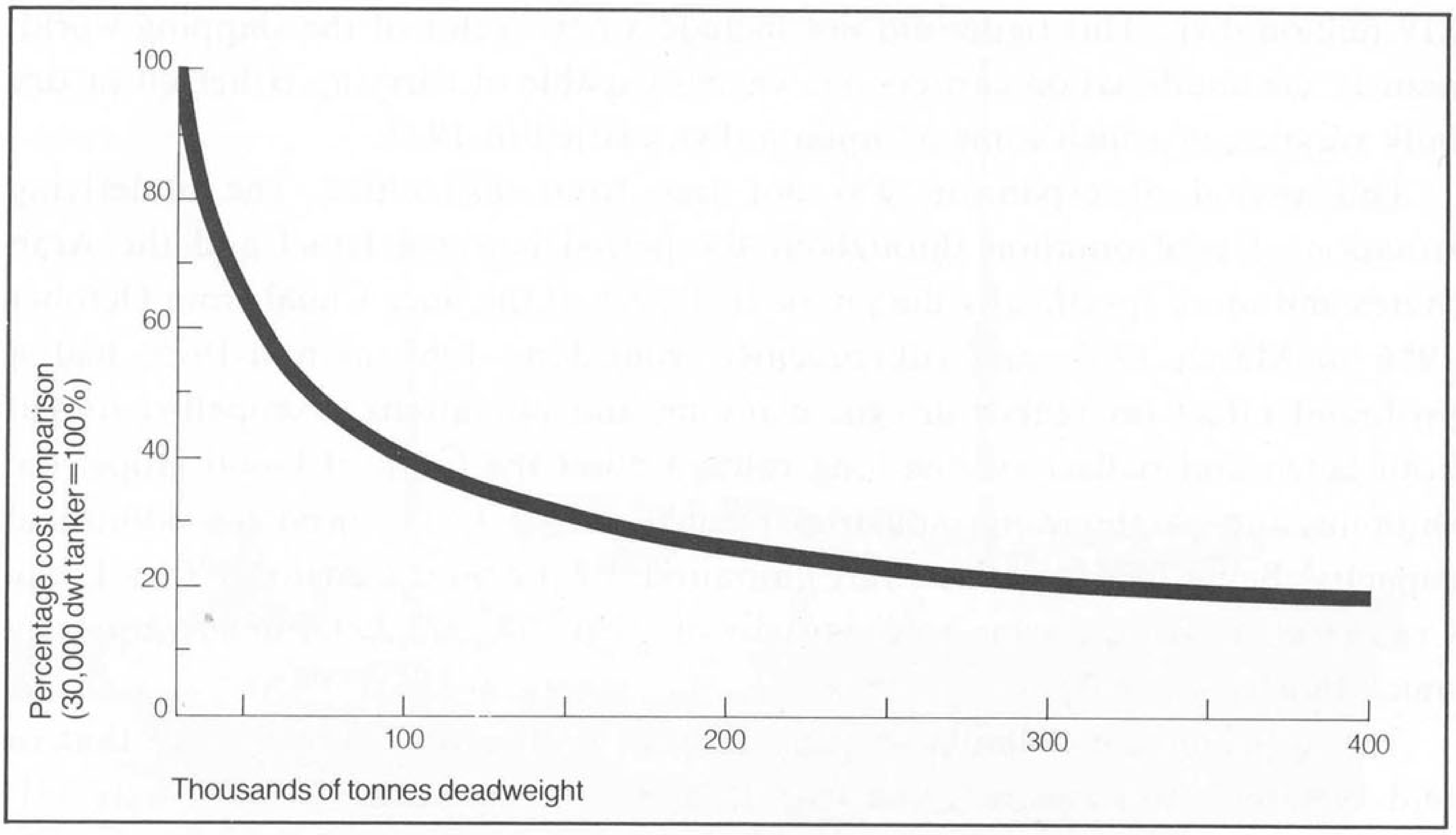

Figure 7.4 **Comparative transportation costs by size of oil tanker**
(Basis: newbuilding capital charge plus owner's and charterer's operating costs – per tonne of cargo)

areas, and lightening at sea, in port, or multi-port discharges became the order of the day. Shell pioneered the expertise required to lighten these very large vessels in open waters.

By this time the pattern of use of various sizes of ships had become more clearly defined. Vessels up to 40,000 dwt. were almost exclusively reserved for the carriage of refined products; the next group up to 100,000 dwt. was used for crude oil supplies to draft-restricted ports; and the VLCCs handled long-haul crude oil movements.

1973 began on a surge of optimism. Continuing substantial growth was foreseen, shipyard order-books were full, and freight rates reached levels hitherto undreamed of, or indeed seen since. The bubble burst in the latter half of 1973/early 1974, when the OPEC countries quadrupled the price of crude oil and progressively nationalised the oil concessions and facilities previously owned by the oil companies. The immediate result of this and later actions by the OPEC producers was to restrict the availability of oil to the consumer countries and to reduce oil demand. This occurred during a period when tanker availability was rising and shipyard order-books were full. Although some orders were cancelled and others rescheduled, the overall size of the tanker fleet continued to increase until 1979 as these new ships were delivered, and had only fallen by about 4 per cent from this peak by the end of 1981.

The period since 1973 has been characterised by rising oil prices. These were given a further sharp boost by the Iranian Revolution in 1979 and the Iran/Iraq war in 1980, and led to a significant drop in the demand for oil and a substantial tanker surplus. Efforts have been made to reduce the tanker surplus by scrapping older vessels (75 million dwt. scrapped in the period 1973/81), the laying-up of idle vessels, and general slow steaming. Demand for tankers, however, continues to fall, current availability of tankers exceeds demand by nearly 50 per cent, and equilibrium between supply and demand still (in the early 1980s) seems a long way off.

The Suez Canal reopened in the middle of 1975 but, because of the advent of the VLCC which was too large to transit the Canal, its significance was much reduced. The Suez Canal Authority then undertook an expansion programme, deepening the Canal so that from mid-1981 vessels up to 150,000 dwt. could safely transit fully laden, and ships up to 350,000 dwt. in ballast. However, the amount of oil moving through the Canal in 1981, about 2.5 million tonnes per month, is still only a fraction of the peak volumes of early 1967. Plans are in hand for further expansion of the Canal, but this may be delayed by current economic conditions and the existence of so much surplus tonnage.

Organisation of the World's Tanker Fleets

Nearly two-thirds of the world's tanker tonnage operates under the flags of five countries. Before World War II the British and Commonwealth flag fleets were larger than those registered under any other flag, but the severe losses sustained by British owners during the war, coupled with the large quantity of wartime tanker tonnage constructed in the USA, brought the latter country into top place by 1945. Subsequently, there were large transfers of US tonnage to other flags, with the result that by 1965 the USA had dropped to fourth place with 11 per cent of the world total. Norway and the UK held second and third places respectively, with 15 and 14 per cent. Japan, with virtually no tanker tonnage after World War II, had risen to fifth place with 5 million tonnes, or 6 per cent, and was still rapidly increasing her tanker fleet. The most striking change, however, has been the emergence of the Liberian flag, from nothing at all in 1945 to first place with $15\frac{1}{2}$ million dwt. in 1965 and 111 million dwt. in 1981, representing 30 per cent of the total. It is interesting to note that tonnage owned by the OPEC countries reached 5 per cent by 1981.

The practice of registering ships in the "open registers" (often called the flags of convenience), of countries such as Liberia, has developed because of the advantages enjoyed by the owners of ships so registered in freedom of choice on crew nationalities/manning scales/financing arrangements and in tax benefits. This has been the subject of considerable controversy at international political level for many years. Certain governments consider that there should be stronger economic links between vessels and the states in which they are registered; clearer definitions as to ownership, manning scales, standards of pay; greater control by the flag countries in enforcing standards of safety. In certain quarters it is further considered that the existence of the open registers acts as a barrier to the ambitions of the developing countries in building up their own national fleets. Other countries, while favouring enforcement of safety standards and greater transparency of ownership, disagree that abolition of the open registers is the best means of achieving these goals.

Apart from considerations of flag, the three main classes of owners are the oil companies, who run their ships as part of an integrated industry; independent owners without any other stake in the oil industry; and governments which in some cases desire, for reasons of internal policy, to control the commercial transport of the oil which they import/export, or to engage in international trade with national flag ships.

Before World War II, more than 50 per cent of total world tanker tonnage was owned by the oil companies, but the rapid post-war expansion in the demand for oil, with its consequent heavy burden of capital expenditure in all segments of the industry, made a reduction in this proportion almost inevitable. Many independent shipowners were quick to foresee the new situation and took steps to increase their share of the tanker trade. Table 7.2 shows the extent of the changes in ownership in the post-war period.

Table 7.2 **Ownership of World Tanker and Combination Carrier Fleet** (Percentage Share)

	Oil companies	Independents	Governments
1957	38	56	6
1961	38	57	5
1971	27	67	6
1981	25	65	10

The role of the independent owner is a vital one. In making their long-term plans for the provision of tonnage, the oil companies, after taking account of their own ships, proceed to charter from the independents the balance of their requirements by an amalgam of long-, medium-, and short-term contracts. In this way the companies are able to obtain the necessary flexibility to cope with fluctuating demand as well as changes in supply patterns.

For all that, the system has its demerits, since the law of supply and demand falls upon a comparatively small amount of marginal tonnage with the result that tanker freight rates for these ships are subject to violent changes. In 1951, 1956, and 1973, when world requirements tended to outstrip tanker availability, rates rose to very high levels; on each occasion substantial newbuilding programmes, which ultimately proved larger than necessary, were put in hand, and these resulted in a surplus of tanker tonnage in the following years and a consequent drop in rates. With the decline in tanker demand which followed the 1973/74 oil price increases, and which shows every sign of continuing in the 1980s, freight rates have remained at depressed levels. The bulk of the surplus tonnage exists in the VLCC/ULCC (Ultra Large Crude Carrier) size ranges, i.e. large crude oil carriers between 160,000 and 550,000 dwt.. Rates for these ships have been so low that they have for long periods not even covered owners' operating costs.

Obsolescence has naturally been a key feature in the struggle to reduce the surplus position. Some years after World War II, tankers were scrapped, on average, after a life of about thirty years. Gradually this was reduced to twenty years for most sizes of tanker, and to considerably less for VLCCs. The average age of the 39 VLCCs scrapped in 1981 was $11\frac{1}{2}$ years.

Class of Tanker

The Modern Crude Oil Carrier

In the early 1960s a typical large crude oil carrier was a ship of 70,000 dwt., optimised for the carriage of a single grade of crude oil from the Middle East to a West European refinery terminal. By the mid-1960s three factors were influencing the thinking of tanker designers:

(i) The major shipbuilders were confident that they had the resources to handle a further jump in size.

(ii) To design on the basis of the much longer voyage to Western Europe via the Cape would require a substantial jump in size if the essential economy was to be achieved.

(iii) The success of the single buoy mooring terminals connected to shore by submarine pipeline made it possible to think in terms of "taking the port out to the ship" instead of having to bring the ship into the port. This freed the design to a significant extent from the constraints imposed by the relatively shallow water access to many ports.

The first VLCCs entered service in 1968. They were mostly of around 200,000 dwt. and powered by steam turbines giving a loaded speed of about 16 knots. The power was delivered by a single screw. Steam was supplied by a single large efficient boiler often in combination with a much smaller "get you home" boiler for use in emergencies. The main engine boiler was also used as the power source for cargo handling equipment which was designed for even more rapid loading and discharge of homogeneous cargoes of crude oil, with a small number of very large cargo compartments and large diameter pipelines. The sheer size of these ships and their equipment as compared with their predecessors, made it necessary (as well as economically desirable) to introduce many features designed to replace manual effort, e.g.:

(i) The mooring ropes and wires could no longer be manhandled, and mechanical systems were introduced.

(ii) The pipeline valves could no longer be turned manually — which led to development of centralised, "push-button" cargo control rooms.

(iii) The engine rooms were too vast for the traditional watch keeping and engine control duties to be undertaken from within. The engine controls and monitors were therefore extensively automated, which made it possible to introduce control of all engine functions from the bridge of the ship.

(iv) The deck and overside areas of the ship were much too large for the traditional maintenance of painting surfaces. This provided the stimulus for the development of new paints capable of surviving much longer in a hostile marine environment.

All these and many more similar developments made it possible for the VLCC to be operated with greater reliability and safety, but with a smaller total complement than the much smaller ships built in earlier years.

Subsequent VLCCs and ULCCs have not changed in basic design in a fundamental sense. The trend towards greater automation was maintained, but the number of separate cargo compartments was increased. This facilitated the use of these ships for carrying more than one grade of cargo.

The increase in size continued steadily for a few more years. However, by the mid-1970s the effects of the oil price increases and the recession in the major oil-consuming nations led not only to the surplus of tanker tonnage already referred to, but also introduced a need for flexibility in shipping that the very largest ULCCs were not well suited to provide. The increase in oil price has also had a profound effect on the thinking of tanker designers on the subject of bunker fuel consumption. A few owners have re-engined VLCCs, replacing steam turbines with diesel engine propulsion in view of the significant reduction in fuel consumption, but it will only be in the future when new VLCCs come to be needed again that the full results will be seen of the designers' efforts to build ships with maximum fuel efficiency.

The Modern Products Carrier

Although the total demand for tankers to carry refined products diminished steadily in the 1970s, a number of newbuildings has been called for each year to replace some of the immense number of such ships built twenty years earlier and thus coming to the end of their economic lives. This has given the tanker designers the opportunity to revise regularly their basic design concepts. Indeed, looking ahead, with the prospect of additional supplies of refined products becoming available from refineries at or near the source of crude oil instead of being sited within the consuming countries, there is the prospect of an increasing need once again for the type of tanker most suitable for the transportation of these products to markets worldwide. There seems little doubt, therefore, that this is a part of the tanker tonnage picture to which designers will continue to pay close attention.

A typical modern products carrier is of approximately 30,000 dwt., and is powered by a slow-speed diesel engine capable of burning heavy fuel oil efficiently. The compartmentation of the cargo tank is such that 6 grades of cargo can be carried with complete segregation, but up to 12 grades if a minimum degree of admixture in the pipelines between certain grades is acceptable. These ships can safely carry "black" and "white" oils in a single cargo, a facility generally lacking in earlier product carriers. Tanks are fitted with steam heating coils so that the heavier grades that require heating to make them readily pumpable can be carried. Vessels of this type are frequently fitted with a waste heat recovery plant so that heat in the exhaust gases can be used to drive generators, thus making it possible to reduce bunker consumption still further.

Perhaps the most marked change from earlier product carriers, however, is in

Figure 7.5 **m.s. *Eburna;* 31,374 dwt. A typical 1979-built products carrier, capable of carrying different grades on the same voyage. Mt. Fuji in the background.**

regard to the manning of these ships. Total complements are in the range of 20 to 25 men, with possibilities of some further reduction. Most routine operations are automated and the engines are capable of operating for long periods unattended.

Luboil Carriers

Lubricating oil, of which there are many grades, is a high-quality product and requires the greatest care in handling if contamination is to be avoided. Sufficient luboil is transported by sea to the world markets to classify this as a bulk movement. Individual parcel sizes are generally small, requiring vessels with a variety of tank sizes with a highly sophisticated pipeline/pumping system so that the many grades can be carried completely free from risk of any contamination between the separate grades of cargo. Thus the trade is ideally suited to be carried by the vessels commonly known as Parcels Tankers. These are very sophisticated vessels of 20,000 to 40,000 dwt. having a high degree of segregation, pipeline and pumping flexibility. Some luboil has for many years been carried in conventional product carriers but the older vessels are fast disappearing. Product carriers of the new generation are nearly twice the size and their tank sizes tend to be too large to accommodate the individual parcels of luboils economically. Thus it is probable that increasing quantities will be transported by Parcels Tankers.

Chemical Carriers

The transportation of chemicals similarly demands a high degree of purity and segregation, calling either for specially protective coatings on ships' tanks, or for stainless steel tanks and pipelines. Because of the large number and diversity of chemical products, special equipment is provided for the cleansing of tanks and lines after each cargo to avoid any possibility of contaminating subsequent cargoes. Vessels are constructed to recognised industry standards.

Bitumen Carriers

Bitumen is solid or nearly solid at ambient temperatures and so in order to carry and easily discharge this product in bulk, vessels have to be equipped to maintain product temperatures in the region of 120°C, depending on grade. Because of the stresses caused by the wide range of temperatures experienced on laden and ballast voyages, vessels are normally strengthened to counter the buckling effect on steel plates which otherwise would occur. The number of large bitumen vessels of 18,000 to 25,000 dwt. has remained fairly stable for several years. There have been a few additions to the number of vessels in the 4,000 to 10,000 dwt. sizes, which handle movements from small production plants, or to markets with low demand, or requiring special grades.

LPG Carriers

In the early days, LPG was compressed into a liquid state to reduce the volume to manageable proportions for transportation by sea. "Pressurised vessels" (i.e. vessels carrying LPG under pressure in tanks) reach their optimum size at around 5,000 cubic metres. Until about ten years ago the major proportion of LPG was moved in this type of ship. There are still some four hundred ships, ranging in capacity from 100 to 5,000 cubic metres, distributing pressurised LPG on coastal and short-distance voyages throughout the world.

With the development of the extraction processes by certain large-volume crude oil producers, e.g. Saudi Arabia, Kuwait, Abu Dhabi and the UK, the availability of LPG for distribution into world markets has gradually increased from about fourteen million tonnes in 1977 to about twenty-five million tonnes in 1982, and is expected to reach around thirty-five million tonnes by 1985. As the major consumers of the increasing supplies of LPG were situated long distances from production areas, cheaper methods of transportation were sought. Reduced costs were achieved by liquefaction by cooling, i.e. by reducing the product

Figure 7.6 **m.s. *Isomeria*; 58,950 m^3; built 1982 by Harland and Wolff. An LPG carrier.**

temperature to between minus 42°C and minus 50°C for propane and to between 0°C and minus 6°C for butane at atmospheric pressure. Both shore and ships' tanks need to be fabricated from special low-temperature steels and insulated. There are various designs of ships' tanks. Due to heat transfer through the insulation, liquid cargo vaporises or "boils-off". To avoid this loss of product, vessels are equipped with compressors and coolers to reliquefy this gas which is returned to the tanks. More importantly, as LPG is heavier than air and can form flammable mixtures when diluted with air, venting of gas to atmosphere is normally prohibited. To give some idea of the growth in the transportation of refrigerated LPG, in the 5 years 1966 to 1970 31 vessels were built of 10,000 to 100,000 cubic metres capacity, whereas in the eleven years 1971 to 1981 some 120 vessels were built or odered, of which 19 are between 50,000 and 60,000 cubic metres and over 50 are larger.

Liquefied Natural Gas (LNG) Carriers

LNG is a very different cargo from LPG. It consists predominantly of methane, but contains other substances such as ethane, propane and butane to an extent which varies according to the quality of the natural gas from which it is made, the demands of the market, and the method of manufacture. Once re-gasified, it is either burned in power stations to generate electricity, or it is supplied to domestic and industrial users as gas.

The natural gas is liquefied by cooling to below its boiling point of about minus 161°C at atmospheric pressure. This means that the ship and shore storage tanks, as for refrigerated LPG, have to be fabricated from special materials and heavily insulated. Even so, some LNG still vaporises on voyage. This "boil-off" gas is piped to the engine room for burning in the ship's boilers. It is possible that future designs of LNG carrier may have diesel engines and reliquefaction plants on board to reliquefy the boil-off gas and return it to the cargo tanks.

The technology associated with the carriage of a liquid at such an extremely low temperature is complex. It is no surprise therefore that these ships are among the world's most expensive types of commercial shipping; for instance, a large new LNG carrier for delivery in 1985 could cost something like $200 million.

Another feature which distinguishes LNG shipping is that, more than in any other trade, the shipping is dedicated to the project producing the LNG and is an integral part of a chain of operations from production through liquefaction and transport to re-gasification and end-use. Hence ships tend to be built for specific projects, and to remain on the same trade route for most or all of their working life. This requires a high standard of performance in every aspect of the operation, from scheduling and time-keeping to operational consistency and safety. In fact, LNG ships have an excellent safety record.

Figure 7.7 **s.s. *Gastrana*; 75,000 m³; built 1974. An LNG carrier dedicated to the "closed loop" Brunei–Japan.**

There are currently 64 LNG carriers with over 25,000 cubic metres cargo capacity, and the majority of them (39) have over 120,000 cubic metres capacity. The largest built to date has 133,000 cubic metres capacity. Since the density of LNG is about half that of oil, and furthermore because of the need to have completely separate tanks for ballast, the dimensions of these larger ships are comparable with those of a VLCC of 200,000 tons dwt. capacity.

While the growth of the world's LNG carrier fleet has been very marked since the first commercially carried LNG cargo was loaded in 1964, LNG still makes up less than 3 per cent of the world's current gas consumption. Nonetheless, if the remotely situated reserves of natural gas are to play their full part in future energy consumption, there will need to be a further significant expansion in the LNG trade.

Offshore Production / Offtake Tankers

No listing of the types of tankers in use today would be complete without a brief reference to the special tasks, often carried on in the most hostile marine environment, associated with offshore oil production. An overall picture of the development of offshore oil fields is described in Chapter 3 (Exploration and Production) and reference is made there to the many different types of mooring and loading arrangements in use, in locations where it is either physically or economically impracticable to construct a pipeline to carry the oil to shore. In such circumstances, existing tankers are often specially modified, or new ships built with the features judged necessary to provide reliable storage and shipping, so essential for optimum production from the field. These mooring and loading systems are frequently based on the concept of the single point mooring, in order to reduce the combined forces of wind, wave, tide and current to a minimum. Because of the inability of support craft to operate in bad weather, systems have been developed whereby offtake tankers can "self-moor". Such tankers are often dedicated to a particular system and have special mooring and bow loading equipment fitted, for example the s.s. Medora on the Fulmar Field in the North Sea (Fig. 7.8).

Figure 7.8 **Floating storage unit on the Fulmar Field (North Sea), showing the converted tanker s.s. *Medora* attached to a single anchor leg mooring. Fulmar A production platform and jack-up rig *Cicero* in the background.**

Systems are now being developed and implemented which, in addition to the storage and offtake functions, have production facilities on the storage unit. Tazerka in Tunisia is an example.

Tankers and the Environment

Safety for both ship and cargo has always been a prime consideration of responsible shipowners, operators and crews. Nevertheless, accidents small and large have occurred ever since men took to sea. With the increased size of tankers these accidents have a far greater impact than ever before on the environment and consequently on the public as a whole. Notably, accidents close to the densely populated areas such as North Western Europe and the seaboards of the United States have attracted much public interest.

It was the grounding of the s.s. Torrey Canyon on 18th March, 1967 on the Seven Stones Reef off Land's End (UK) which drew the attention of a worldwide public to the consequences of a major tanker disaster. However, the biggest oil pollution involving a tanker that the world has ever witnessed occurred on 16th March, 1978 when the Liberian tanker m.s. Amoco Cadiz ran aground off Portsall on the Brittany coast of France.

In the 11 years between these two tanker disasters there were unfortunately several other marine casualties involving tankers that resulted in loss of life and/or substantial pollution of coastlines. The ensuing investigations into the causes of these accidents revealed that, whereas in some cases a major contributing cause has been a failure of equipment, more frequently the underlying error could be traced back to human failure — a lack of competence in navigation, in basic seamanship in the operation of the equipment available on the ship, or in the appreciation of a situation of potential hazard until it was too late for corrective action to be effective.

The years since s.s. Torrey Canyon have been a period not only of intensive study and research, but also of action by governments and by the oil and shipping industries aimed at achieving substantial improvement in regard to safety and pollution avoidance. Action has been taken along several different lines, including:

(i) Changes in the design requirements for new ships to segregate completely the carriage of oil cargo from the carriage of water ballast, and to limit the size of individual tank compartments.

(ii) Changes in operational procedures and equipment on all tankers, existing as well as newbuildings, aimed at ensuring that any ballast water pumped into the sea could not contain residual oil particles, and that the navigational equipment available on board was substantially improved.

(iii) The installation of inert gas systems on all large tankers, which make it virtually impossible for a potentially explosive mixture of air and hydrocarbon gas to exist anywhere in the ship.

(iv) A uniform approach internationally to the standards of training and competence of sea-going personnel.

(v) The improvement and dissemination of knowledge worldwide on the techniques appropriate for the clean-up work after an oil spill and the provision of equipment in suitable locations.

(vi) The establishment of funds which can be made available quickly following an oil spill, so as to ensure that clean-up efforts are nowhere frustrated through lack of funds and to ensure that genuine third party damage is effectively compensated.

No-one connected with the industry would claim that the possibility of serious marine accidents has been eliminated. The sea remains an often difficult and sometimes hostile environment and accidents will happen. It is, however, generally believed that significant progress has been made with tanker operations in making the sea a safer and a cleaner place. Good operating practice in the tanker industry can thus be seen to incorporate two main objectives:

- The provision of an efficient oil transportation service, flexible enough to adjust to changing patterns of trade, at reasonable cost.
- The operation of this service in accordance with the international community's rising expectations for safety and environmental standards.

There is no conflict between these two objectives.

PIPELINES

Most industrialised countries have long had large networks of pipes for the distribution of water and gas, whilst pipelines to move commodities over long distances originated in the oil industry well over a century ago. The first successful crude oil pipeline was built in 1865 in Pennsylvania, a screwed cast-iron pipeline of 2 inch (5 centimetres) diameter and six miles (9.7 kilometres) length. Its life was short for it was torn up by the infuriated Teamsters it had put out of work, but it demonstrated the feasibility of the method.

The three basic functions of pipelines in the oil and natural gas industry are:

(i) To transport crude oil, from oil fields on land or offshore to terminals for export, and from import terminals and oil fields on land to refineries.

(ii) To carry refined products from refineries or tanker terminals to consumers or local distribution depots.

(iii) To transport natural gas from the fields to local distribution centres, or direct to large consumers.

Pipelines are designed and constructed in such a manner that the transport of

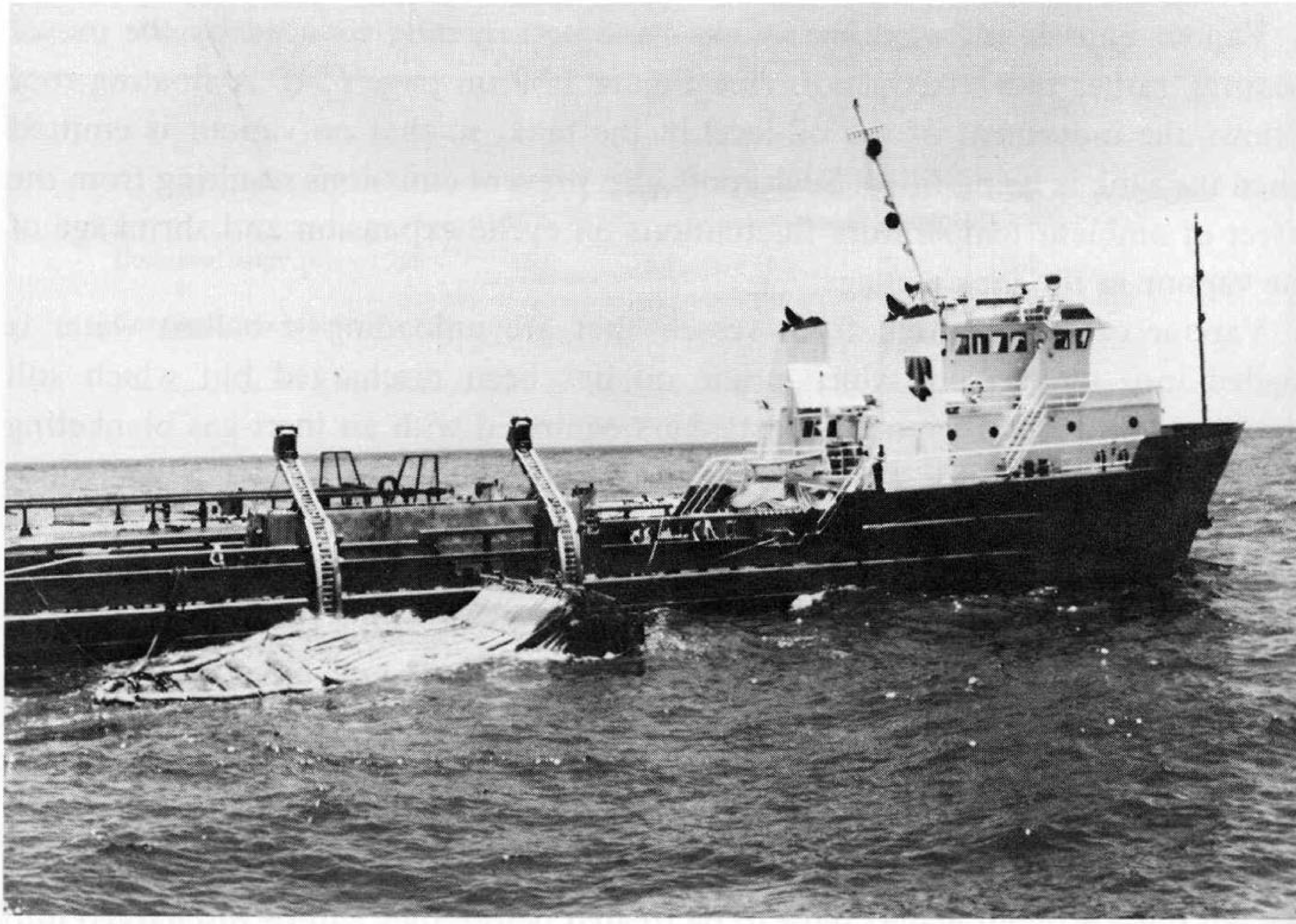

Figure 13.5 **The SOCK (Spilled Oil Containment Kit) Skimmer specially developed by Shell Development Company in the USA for use offshore.**

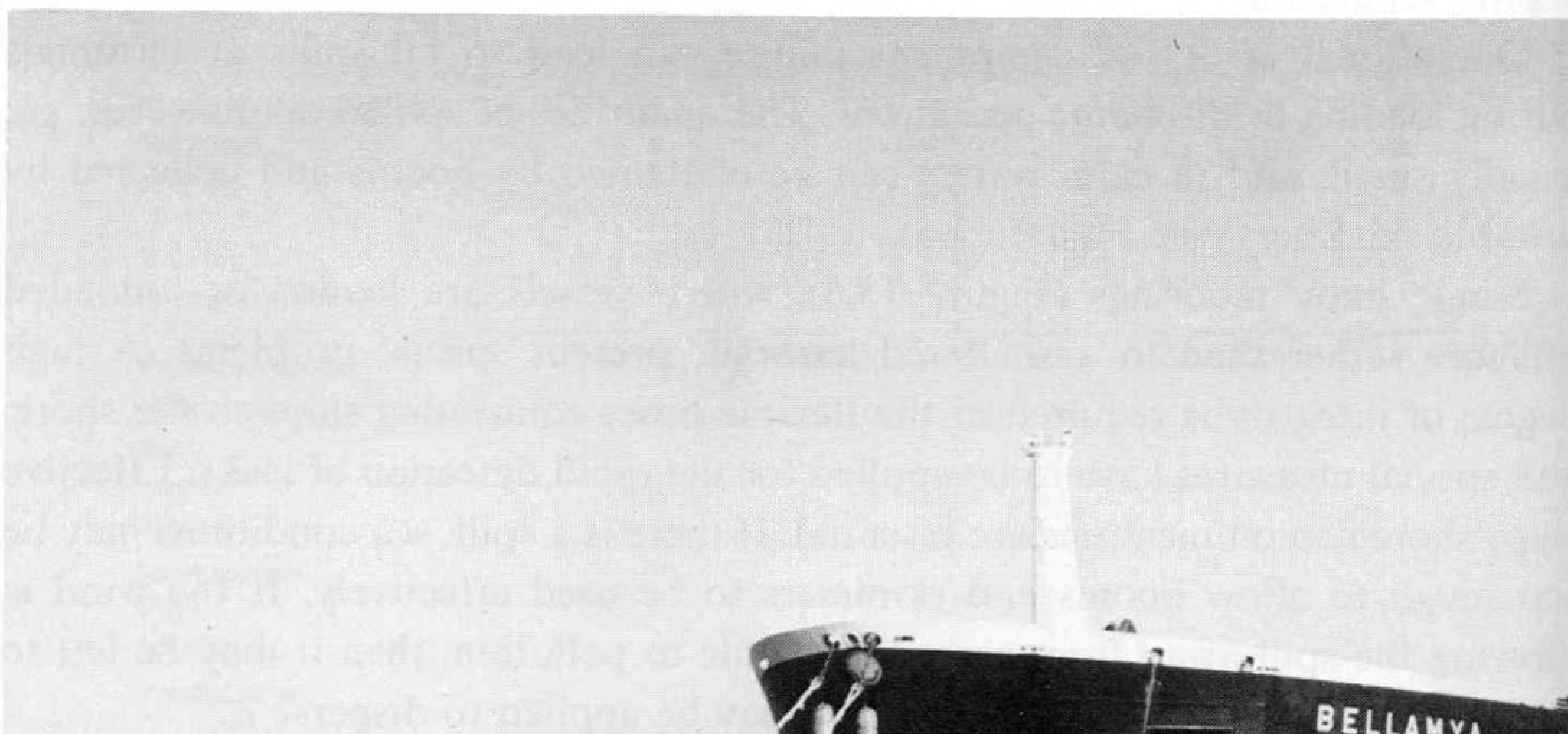

Figure 13.6 **The 550,000 deadweight tonne Shell tanker *Bellamya* loads crude oil through the single buoy mooring at Mina al Fahal in the Oman.**

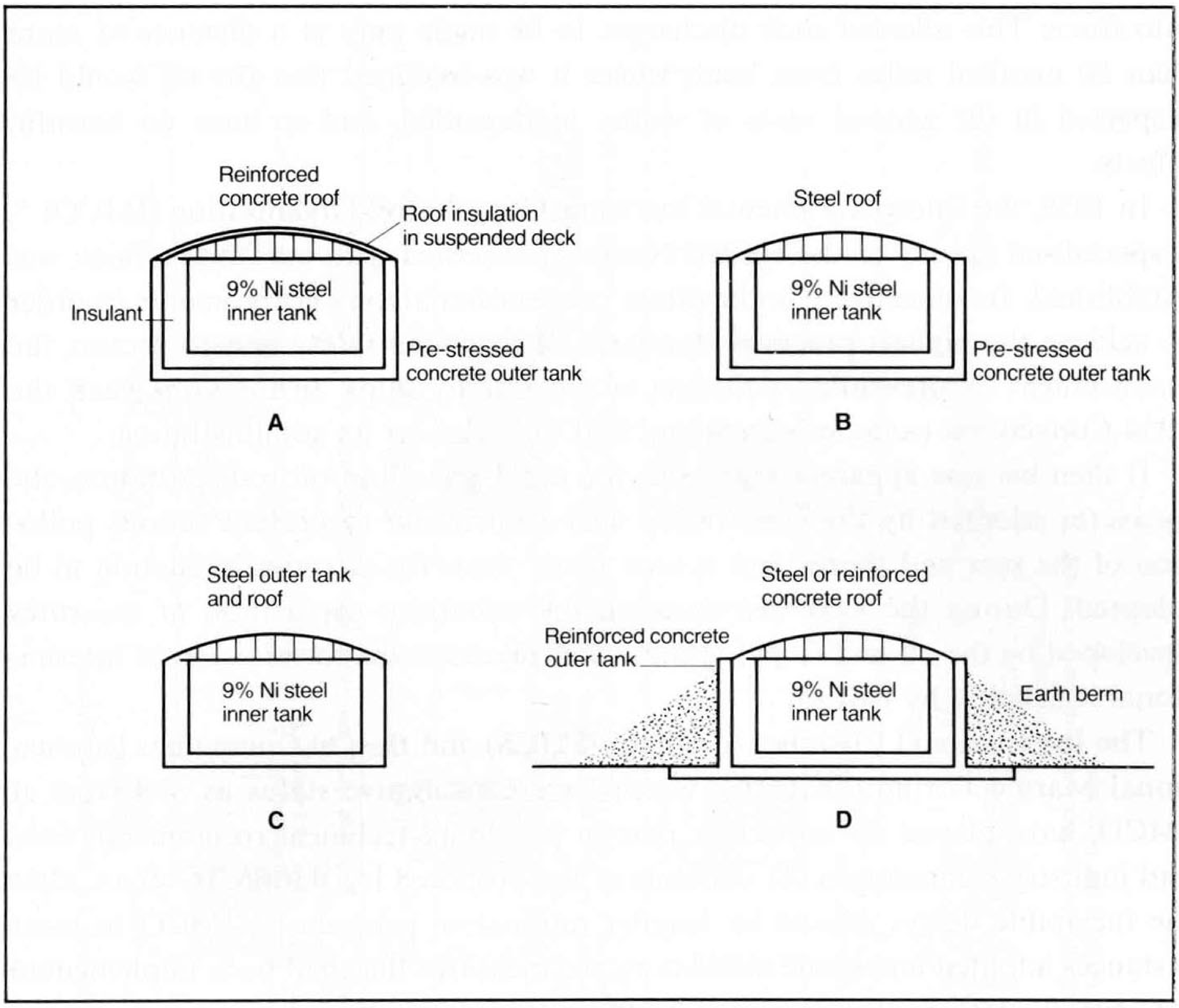

Figure 13.7 **Concepts for double containment refrigerated LPG storage tanks**

Special constructions of various kinds — all considered to be acceptably safe under the given conditions — are used for refrigerated storage tanks. Figure 13.7 shows a diagram of a double integrity tank.

The design of the loading and unloading facilities, and their operation, also need special care with a view to minimising the risk of fires and explosions. The greatest risk, however, is associated with the possible collision and stranding of tankers carrying the liquefied gas in the harbour approaches to the terminal. The siting of a new gas terminal, therefore, is usually the subject of extensive risk analyses, in which considerable attention is given to the tanker approach routes.

Oil Tankers

Tankers have, in the past, caused pollution by discharging into the sea ballast and tank wash water that contains oil — a common practice even after the 1954 International Convention for the Prevention of Pollution of the Sea by Oil came into force. This allowed such discharges to be made only at a distance of more than 50 nautical miles from land, where it was assumed that the oil would be dispersed in the general mass of water, biodegraded, and so have no harmful effects.

In 1958, the Intergovernmental Maritime Consultative Organisation (IMCO) *, a specialised agency of the United Nations concerned with maritime affairs, was established. Its objective is to facilitate cooperation among governments in order to achieve the highest practical standards of maritime safety and to protect the environment by preventing pollution of the seas by ships. In the same year, the 1954 Convention came into force and IMCO took over its administration.

It then became apparent that, with the rapid growth in oil transportation, the measures adopted by the Convention were insufficient to prevent serious pollution of the seas and shores, but it took many years for effective legislation to be adopted. During the next two decades, the voluntary application of measures developed by the oil and shipping industries preceded the formulation of international legislation by IMCO.

The International Chamber of Shipping (ICS) and the Oil Companies International Marine Forum (OCIMF), which have consultative status as observers at IMCO, have played an important part in providing technical recommendations and industry comment on the contents of the proposed legislation. In effect, after the inevitable delays caused by lengthy ratification procedures, IMCO in most instances adopted and made mandatory the measures that had been implemented for several years on vessels owned by the major oil companies.

In the early 1960s, in the absence of shore facilities capable of receiving and treating contaminated water from tankers, the oil industry developed a procedure for treating oily water aboard ship. Known as the "Load on Top" system (see Figure 13.8), oil companies introduced this procedure to their own fleets and also required its application on their time-chartered vessels. In 1969, the procedure was incorporated in amendments to the 1954 Convention and finally became mandatory when these amendments came into force in 1978. The same legislation prohibits the discharge of oil or oily effluents anywhere at sea, except under very stringent conditions and in such concentrations and quantities that no harm will be caused to the marine environment.

Another way of reducing considerably the need to wash tanks for ballast purposes is to use segregated ballast tanks, the water in which is never contaminated with oil. It is a legislative requirement (Marpol Convention 1973 and Protocol 1978) that all new large tankers be equipped with such tanks, and this

* In May, 1982, the name of this organisation was changed to the International Maritime Organisation (IMO).

HOW LOAD ON TOP WORKS

After discharging its cargo a tanker needs to take large quantities of sea water into its tanks to serve as ballast. Tanks must be cleaned at sea to ensure this ballast water is oil-free when it is pumped back to the sea near the loading port.

Tank washings from a 30.000 d.w.t. crude oil carrier could contain 120 tons of oil. In the 'Load on Top' system this oil is separated from the water and kept on board

Dipping a tank to establish the interface between oil and water. When discharging clean water under a layer of floating oil, great care is taken to ensure that the oil is retained on board and not pumped into the sea.

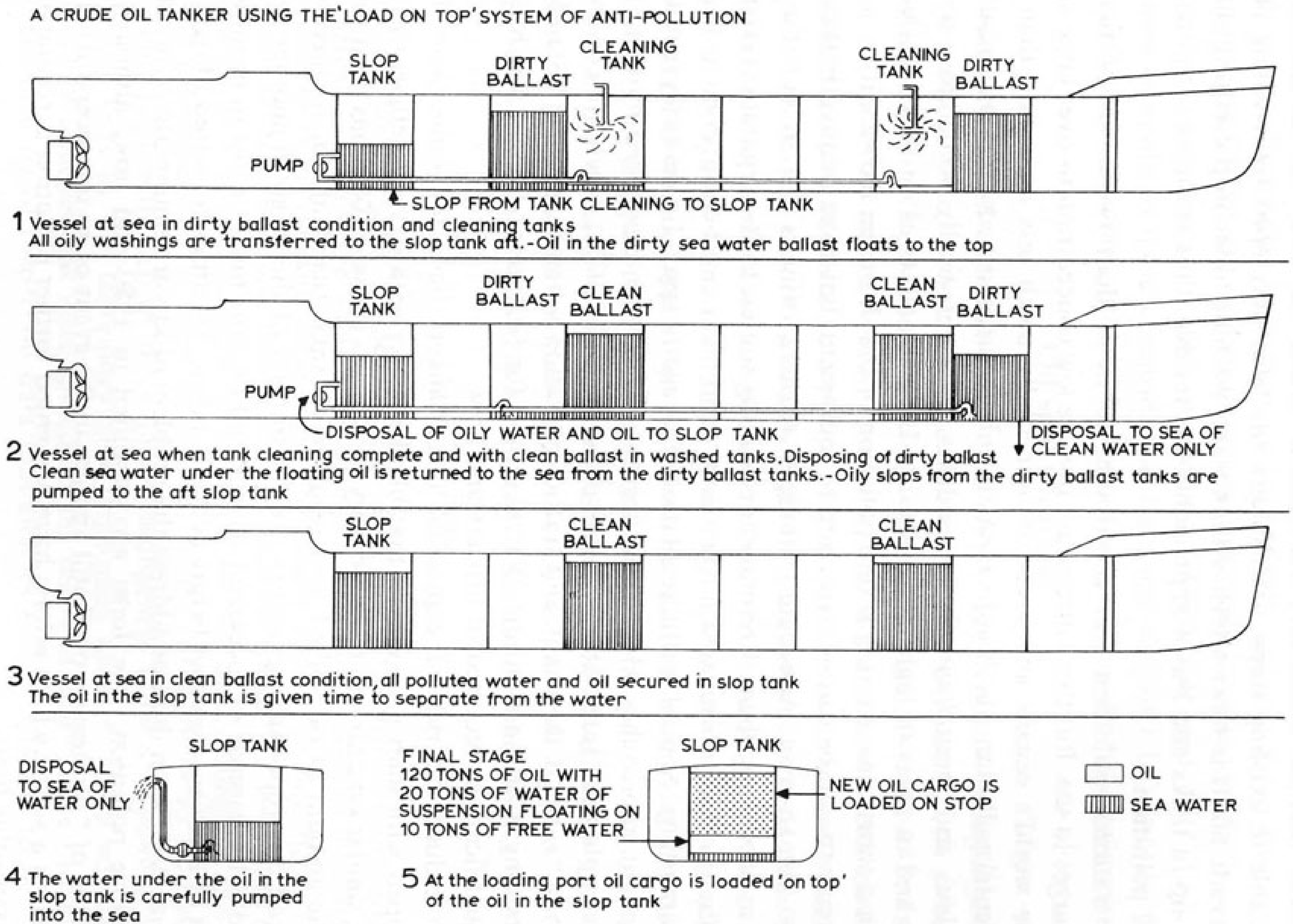

Figure 13.8 **The Load on Top system.**

will soon become mandatory for smaller vessels as well. As an alternative, applicable to existing ships, a technique has been developed for washing tanks with crude oil. It is more effective than water washing alone in preventing sludge build-up in tanks and leaves appreciably less residue, thus reducing the potential for oil pollution.

Operational pollution still contributes to more than two-thirds of the oil discharges to sea. But these discharges involve low concentrations over large areas of the world's oceans and are environmentally much less damaging than the accidental pollution which unfortunately still occurs, most seriously as a result of collisions and groundings. Such accidents characteristically occur close to the shore and in areas of high traffic density. Large amounts of oil may be released within a short time, causing severe pollution of the shores in the vicinity.

Accidents can be caused by failure of equipment, but most frequently they are due to human error. Adequate training of masters, officers and crews is the key issue in preventing them. Recommended sailing routes, traffic separation schemes and the use of sophisticated navigational equipment can help prevent collisions and strandings. Special traffic regulations frequently apply for oil and gas tankers in harbour approaches. Here again, legislation has been developed by IMCO — for example the "International Regulations at Sea" (1972), which are concerned with the "rules of the road" and traffic separation schemes, and the "Standards of Training, Certification and Watchkeeping for Seafarers" (1978), which cover the qualifications required of officers and crew.

To reduce the risk of explosion, large tankers have for some years been equipped with inert gas systems that blanket tanks with oxygen-deficient gas. In 1985, similar systems will be mandatory for tankers above 20,000 tons deadweight.

The amount of oil spilled as a result of a tanker accident can frequently be reduced by proper salvage action and/or transfer of the cargo to another vessel. Speed is the essence of successful salvage and no time must be lost in negotiating terms of a salvage contract before action is taken. The time-honoured Lloyds "no cure no pay" form did not address the problem of salvor remuneration for efforts to reduce pollution. The form was modified in 1980 and now, although the principle of "no cure no pay" still applies, in the event of an unsuccessful salvage operation a salvor whose efforts have prevented further pollution is recompensed on a cost-plus basis.

Despite every effort, tanker accidents and consequent pollution can never be entirely avoided. So as to provide fair and quick compensation for governments and people who suffer damage from such pollution, the tanker industry, in the late 1960s, entered into a voluntary agreement "The Tanker Owners Voluntary Agreement Concerning Liability for Oil Pollution" (TOVALOP). A complementary scheme introduced by the oil companies in 1971, takes the form of a "Contract Regarding an Interim Supplement to Tanker Liability for Oil Pollution" (CRISTAL).

Two intergovernmental schemes — the Civil Liability Convention (CLC), which is broadly similar in format to TOVALOP, and the Fund Convention, which mirrors CRISTAL, came into force respectively in 1975 and 1978 and are adopted by a growing number of nations. TOVALOP and CRISTAL will continue to apply to those countries that have not ratified CLC and the Fund Convention, but the conventions will progressively replace the voluntary schemes.

Oil-spill Clean-up

The best way to deal with an oil spill is to remove it physically, though this may not be practicable in open, unprotected waters, where equipment such as booms and skimmers is ineffective. In such circumstances, provided that there is minimal threat to the environment, the oil can be left to disperse and break down by natural forces. Should there be a potential threat to the environment in circumstances where the oil cannot be readily collected, dispersants sprayed from boats or aircraft can be used, subject to agreement from the relevant authorities.

Special emergency plans for dealing with large spills have been developed by individual oil companies and by governments. In addition, regional plans (usually joint efforts by groups of oil companies and/or governments — depending on the part of the world concerned) have been evolved to cover wider areas and incidents too large for one company alone to cope with effectively. They may also be applied by governments where a spill may cross national borders.

Gas Carriers

A high standard of safety is especially important during the marine transportation of liquefied gas, since the ships carrying it are usually required to discharge at ports near to industrial and urban areas. No major spillage of liquefied gas has yet occurred, but there has been much speculation about the possible consequences of such a spillage both to the ship and its surroundings. Long-term research programmes have been carried out by the oil industry to help clarify what might happen in such an unfortunate contingency. These have involved both small-scale tests in the laboratory and large-scale tests in which substantial quantities of liquefied gas were spilled on the sea. The results have provided a comprehensive set of dispersion data that enables safety distances to be calculated, as well as information that can be used to assess the vulnerability of gas carriers to fire or explosion.

OIL REFINERIES AND PETROCHEMICAL PLANTS

Large complexes of installations such as normally constitute an oil refinery or a petrochemical plant can affect the environment in various ways. They can, for