MARINE APPLICATIONS OF STIRLING CYCLE REFRIGERATORS

Ir. R. E. Meulenberg* and T. W. D. Abell, C.Eng. (Member of Council†)

The generation and application of low temperatures, between ambient and −200°C (−328°F) are long known techniques. However, the application of cryogenic temperatures between −100°C (−148°F) and −200°C (−328°F) has been extended to a wider and more popular range only for the last twenty years.

All refrigeration systems are characterized by expansion at low, and compression at high, temperatures of some cycle medium. In contrast with other systems the Stirling refrigeration cycle makes it possible to incorporate all the required machine components such as compressor, expansion machine and heat exchangers in one compact unit.

This design makes Stirling cold gas refrigerators, by nature most suitable for the temperature range −100 to −200°C (−148 to 328°F), attractive for marine applications.

Present and possible future marine applications of cold gas refrigerators are:

a) reliquefaction of flash from a liquid gas cargo like ethylene or methane;
b) production of pure nitrogen gas to purge or protect explosive or oxygen sensitive cargoes;
c) production of respiration oxygen for the aircraft in carriers;
d) production of liquid nitrogen for supply to deep freeze containers in container ships;
e) production of liquid air for shock freezing of the more expensive fish and shell fish.

Ir. Meulenberg

Mr. Abell

INTRODUCTION

Historically, the first known human activities, in cooling down or refrigerating subjects or material below ambient temperature, originated in Egypt. The most simple form of refrigeration by evaporation of liquid at the surface of porous pottery was used, in order to cool down or to maintain lower temperatures of drinks, stored in these earthenware pots. But to provide water ice, even the Romans, had to explore natural sources, e.g. distant mountain summits,

In the 19th century, machinery was first described with which temperatures lower than ambient could be generated. Even today only a few, mainly rather complicated, systems for the generation of low temperatures are known, while the systems in practical use number even less. A short résumé of these processes is given here.

The most popular and probably oldest method of producing a temperature drop is cooling by evaporation. A liquid is evaporated, equilibrium between liquid and vapour being prevented by discharging the vapour and the evaporation thus proceeding undisturbed. During evaporation a quantity of heat or a heat content is consumed and the liquid cooled down. An example of this simple method is the use of porous pottery, already mentioned. Here the cooling down of the liquid content is achieved by the slow evaporation, at the outer surface of the pot, of the same liquid, conveyed to the surface by the pores.

A continuous operation installation, on this principle, is achieved where the refrigerant vapour is reliquefied at a point other than that of evaporation. The vapour is drawn from the evaporator, compressed and recondensed, and returned to the evaporator. These compression-evaporation refrigerators are those most used.

Another type working on the same basic principle of evaporation cooling is the absorption refrigerator. In these plants the vapour from the evaporator, is drawn away into an absorbing liquid, at another part of the system. By boiling the saturated absorbing liquid then reliquefying the refrigerant vapour, liquid refrigerant can be returned to the evaporator.

The lowest temperatures produced economically by these systems, are limited mainly by the decrease of the vapour pressure of the refrigerant according to the temperature drop. At low temperatures, the specific volume and so the total volume of the vapour to be drawn away, is so large, that the machinery becomes too bulky. Therefore, temperatures between −60°C (−76°F) and −80°C (−112°F) are considered as being the economical limit for these closed loop evaporation systems. For example, dry ice, solid carbon dioxide, is produced in this way at −78°C (−108°F) and 1 atm in high tonnage plants.

If temperatures lower than −80°C (−112°F) need to be achieved, two or more successive closed loops can be supplied, each with its own and, in connexion with temperature range, most suitable cycle refrigerant. These so called "cascade" systems are rather complicated and bulky and, therefore, not to be preferred, especially for small units, where specialist staff are not available.

Refrigeration systems based on different principles from the evaporation plant described are used for liquefaction of air nitrogen and oxygen, i.e. gases having liquefaction temperatures

---

* Department Manager, Cryogenic Products, Werkspoor-Amsterdam N.V.,

† Consultant Engineer, Netherlands Dock and Shipbuilding Co., Amsterdam.

at 1 atm in the range of −180°C (−292°F) to −200°C (−328°F).

The first industrial plants for liquefaction of air followed by separation into oxygen and nitrogen, as described and applied by C. von Linde, originate from about the year 1900. These installations were based on the Joule-Thomson effect, i.e. the temperature drop of a gas, which occurs with all gases below a certain inversion temperature, where a pressure drop occurs through an expansion valve.

The Claude process also originates from the same period. Here the temperature drop of a compressed gas is caused by adiabatic expansion in an expansion chamber while mechanical work is provided simultaneously by the gas. All modern air liquefaction and separation plant are based on a combination of the "Linde" and the "Claude" processes.

Although both basic processes are most suitable for the −180 to −200°C (−292 to −328°F) temperature range, they can be and are applied to other temperature ranges, to the −250 to −270°C (−418 to −454°F) of liquid helium and hydrogen temperatures, as well as to temperatures around −160C° (−256°F) for natural gas, i.e. methane, liquefaction units. There are few other economical alternatives for the range −250 to −270°C (−418 to −454°F), while the range around −160°C (−256°F) can be covered by cascade linking compression-evaporation cycles.

In the temperature range, −100 to −180°C (−148 to −292°F), the requirements for small, simple and easy to handle refrigeration machinery are difficult to satisfy. The process and machinery based on the Stirling cycle, cover this range, from −100 to −200°C (−148 to −328°F), quite satisfactorily.

The Stirling cycle itself is not new and was used in a refrigerating machine by A. G. Kirk in 1873. In those days, however, there was still little knowledge about materials and heat transfer problems, closely associated with design and manufacture, especially with machines operating on the Stirling principle. The present state of engineering opened up new possibilities for this sort of machinery, by which temperatures between −100 and −200°C (−148 and −328°F) can now be generated in one stage by simple, easy to handle, equipment.

THE COLD GAS REFRIGERATOR OPERATING ON THE STIRLING CYCLE

The cold gas refrigerator (CGR) incorporates all components of a closed refrigerant loop in one machine, i.e. the compressor, expansion machine and heat exchangers are assembled into one unit. This is the opposite to other refrigerating machinery in common use.

Schematic Cycle

This can be described by reference to a schematic cycle in which the piston movements do not occur simultaneously but one after the other (see Fig. 1). The gas circuit comprises the compression chamber, a cooler externally cooled by water, a regenerator, a condenser, externally heated at low temperature by the medium to be cooled or condensed, and the expansion chamber. The closed circuit of the CGR contains hydrogen or helium as the refrigerant which remains in the gaseous state throughout a complete cycle.

The schematic cycle involves the following piston movements:

Phase I–II:	the piston moves upwards and compresses the refrigerant gas present in the compression chamber. The displacer does not move during this compression stroke.
Phase II–III:	the displacer moves downwards, causing the compressed gas to flow from the compression chamber to the expansion chamber, through the watercooled cooler, regenerator and condenser, all annularly arranged around the displacer. When passing the cooler, the heat of compression is discharged from the refrigerant by the external water flow. Furthermore the refrigerant gas releases heat to the regenerator, i.e. sensitive heat of the gas is absorbed by and stored in the regenerator's copper gauze material. If the temperature distribution in the CGR is in equilibrium, the refrigerant leaves the regenerator already at a low temperature, i.e. a temperature almost equal to the operation temperature of the condenser.
Phase III–IV:	the piston and the displacer move downwards together, causing the refrigerant gas to expand and drop its temperature to a lower level than the operating temperature of the condenser.
Phase IV–I:	whilst the piston remains stationary, the displacer moves upwards and displaces the refrigerant gas from the expansion chamber through the condenser, the regenerator and the cooler back to the compression chamber. Because the expanded gas now has a temperature lower than the operating temperature of the condenser, it is capable of absorbing heat from the medium, which has to be cooled or liquefied, and is passed through the condenser from outside. As the refrigerant flows through the regenerator, it picks up again the stored sensitive heat from the regenerator material. By this time the start condition of the first phase has been restored and thus the closed cycle of the refrigerant gas has been completed.

The cycle movements of the piston and the displacer are obtained by means of a rhombic drive mechanism. The cycle process is repeated 1500 or 1800 times per minute, dependent on the frequency, 50 Hz or 60 Hz, of the electric power supply to the driving electric motor.

The gas in the closed circuit must remain in the gaseous state throughout the complete cycle, i.e. the condensation temperatures of this gas at the pressures prevailing in the refrigerator have to be low enough for no condensation of the cycle gas to occur. Furthermore, the properties of the cycle gas should approximate as closely as possible those of an ideal gas. For these reasons only hydrogen or helium can be used as the cycle gas.

Rhombic Drive Mechanism

The rhombic drive mechanism shown in Fig. 2 consists of two crankshafts coupled by means of gear wheels. The two

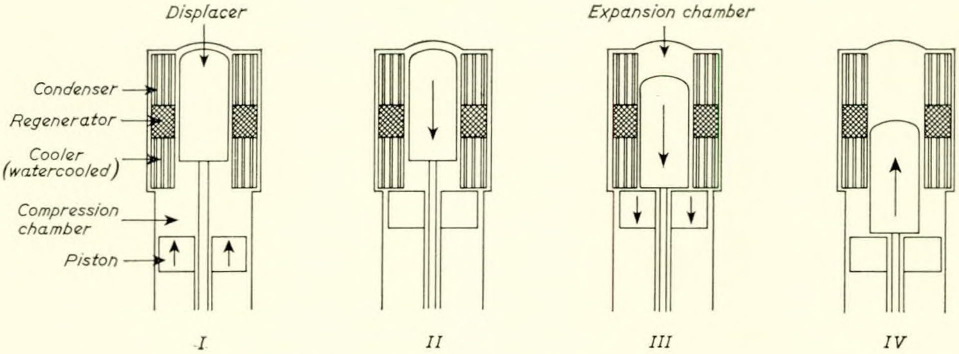


FIG. 1—*Schematic cycle of cold gas refrigerator*

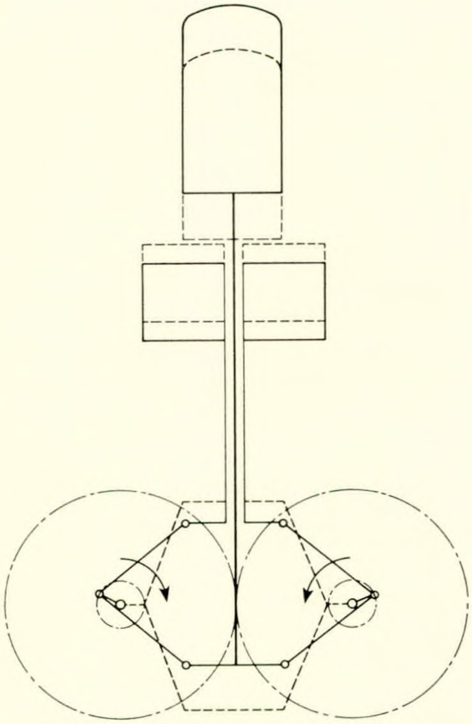


FIG. 2—*Rhombic drive mechanism*

cranks, rotating in opposite directions, are each connected by rods to the piston rod yoke and also to the displacer rod yoke. As can be seen from the figure, the motion of the displacer yoke, complete with displacer rod and displacer, has a phase lead of approximately 90° on the motion of the piston yoke, complete with piston rod and working piston. This phase difference means that the required movements of piston and displacer, as shown and described in Fig. 1, will be achieved, not one after another but harmoniously and gradually. For ship use, an important advantage is that the rhombic drive mechanism ensures complete balancing of each cylinder unit, ensuring vibration-free operation without special foundations.

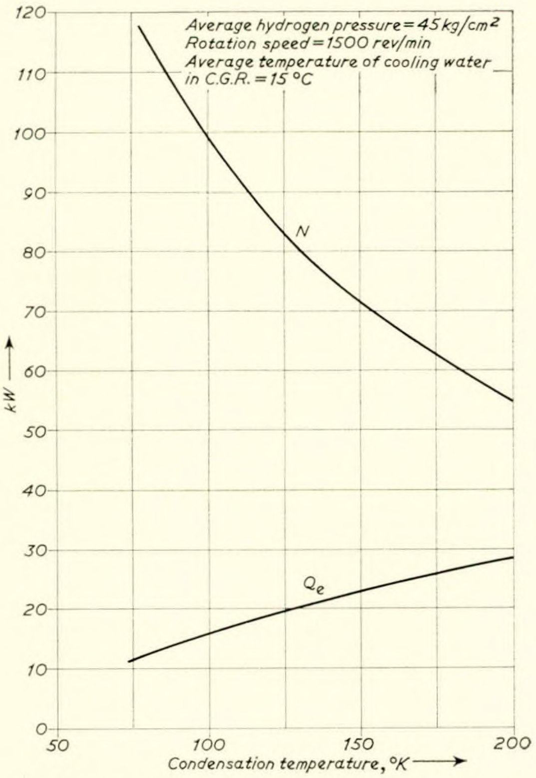


FIG. 3—*Refrigeration capacity Q_e and shaft power N of single-cylinder CGR*

Refrigeration Capacity and Power Requirements

The heat absorbed at low temperature in the condenser by the refrigerant gas from the gas to be cooled and liquefied constitutes the refrigerating capacity of the CGR. The refrigerating capacity, as well as the pertinent required shaft power, depends on the condensation temperature of the gas to be liquefied, the temperature of cooling water supplied to the cooler, the average pressure of cycle gas and the speed of rotation (see Fig. 3).

If the CGR is used for liquefaction purposes, the gas to be condensed is sucked in by the operation of the condenser itself, within certain limits of flow resistance. There is no need to adjust the operating temperature of the condenser, because this will adjust itself, i.e. the temperature of the condenser will drop until the liquefaction temperature of the gas to be liquefied is achieved at the prevailing pressure. As soon as liquefaction starts and a heat flux to the cycle gas begins, the temperature of the CGR condenser ceases to drop.

As the gas to be condensed contacts no piston, an oil-free condensate can be delivered, while condensation pressures up to 40 atm can be handled.

The heat content corresponding to the refrigerating capacity and shaft power has to be discharged from the system by the cooling water flow.

The refrigerating capacity at a given temperature of cooler and condenser and at a given rotation speed can be adjusted by controlling the quantity of refrigerant gas in the cycle. Thus it can be increased or decreased respectively by increasing or decreasing the cycle gas pressure. Because capacity control is important to the user this subject is dealt with in more detail under a separate heading.

Cross-section of CGR

Fig. 4 shows a cross-section of the CGR.

Besides the supply line for the gas to be condensed and the discharge line for the condensate, the condenser has an additional discharge line for non-condensable gases—the small fraction of gases with which the gas to be condensed is sometimes mixed and which have a lower condensation temperature. As condenser and regenerator operate with low temperatures, they are insulated with perlite powder between the cycle housing and the insulation cap.

A buffer space is provided beneath the working piston which serves to reduce the pressure variations of the gas below the piston to a minimum, avoiding high loads on the drive mechanism.

The sealing along the displacer between the expansion chamber and the compression chamber and that along the working piston between the compression chamber and the buffer space is provided by dry-operating reinforced Teflon piston rings.

For sealing the buffer space and the cycle space from the atmosphere in the crankcase, two stuffing boxes are arranged, one at the bottom of the buffer space along the piston rod and one —not visible in the cross-section—connected to the piston rod yoke along the displacer rod.

A pump driven by the rhombic drive supplies lubricating oil to all bearings and to the bypass valve. The latter is opened in the event of failure of the lubricating oil supply or if there is no oil pressure during starting-up. The compression chamber of the cycle is then in open communication with the buffer space. Consequently it is not possible to build up a pressure differential across the piston and the drive mechanism will run unloaded. A maximum pressure valve and a minimum pressure valve are connected to the cycle space. These serve respectively for discharge and supply of refrigerant gas from and to the cycle space. Supply takes place via the "P minimum" valve, during the period

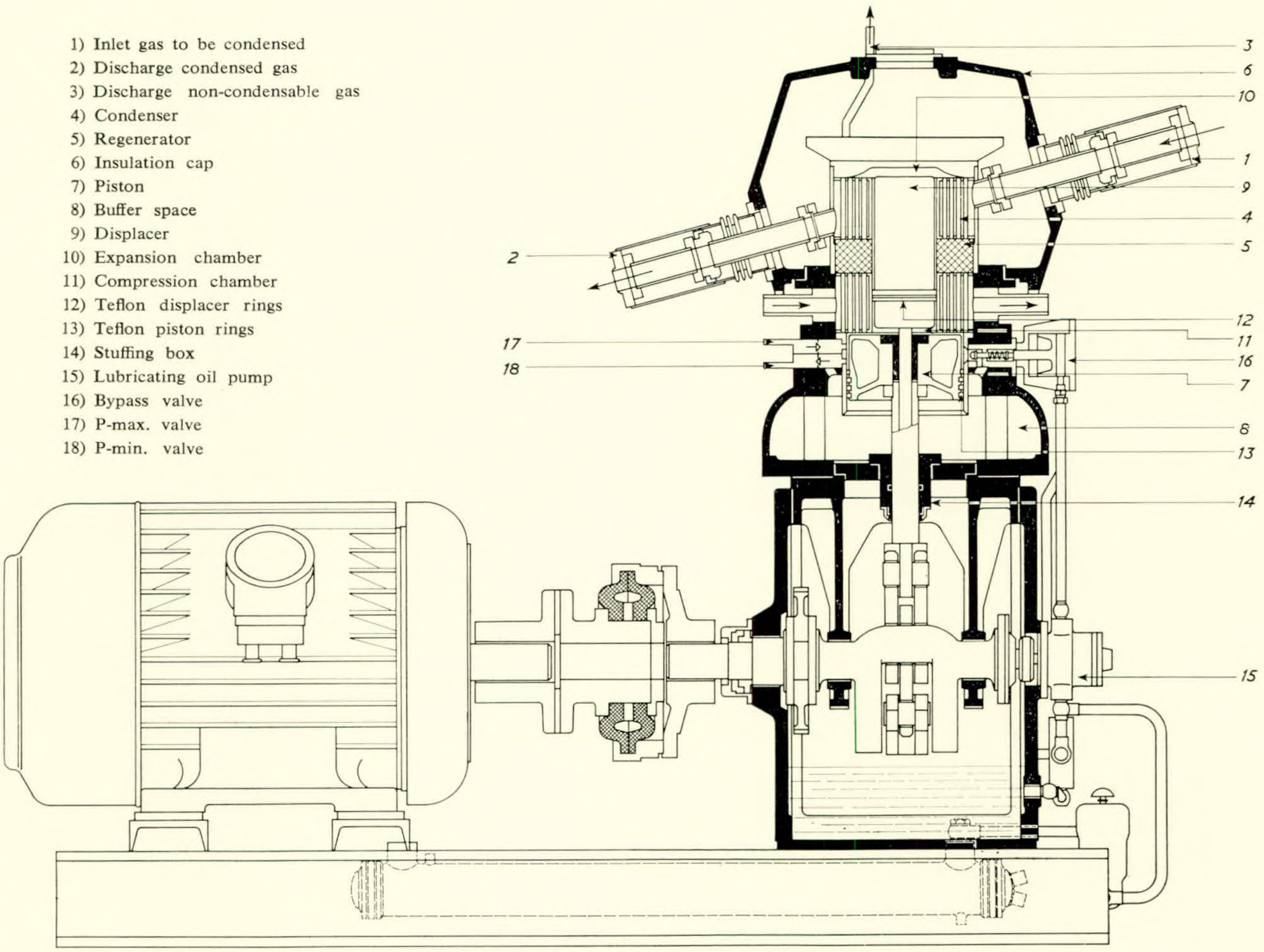

1) Inlet gas to be condensed
2) Discharge condensed gas
3) Discharge non-condensable gas
4) Condenser
5) Regenerator
6) Insulation cap
7) Piston
8) Buffer space
9) Displacer
10) Expansion chamber
11) Compression chamber
12) Teflon displacer rings
13) Teflon piston rings
14) Stuffing box
15) Lubricating oil pump
16) Bypass valve
17) P-max. valve
18) P-min. valve

FIG. 4—*Cross-section of the Werkspoor cold gas refrigerator*

of the cycle when the lowest pressure prevails, while discharge takes place via the "P maximum" valve, during the period of the cycle when the highest pressure prevails.

Adjustment and Control of the Refrigeration Capacity

Shown in Fig. 5 is the simple control system by which refrigeration capacity can be manually adjusted while using the compression ratio of the CGR itself for the supply and discharge of cycle gas from the CGR to the gas buffer and back again.

The cycle gas originates from a set of standard commercial high pressure, 150 atm, gas Bottles (101). By means of the reducing valves (103) and (105) the minimum cycle pressure, pertaining to the required maximum load, is adjusted and maintained after the reducing valve (105). The gas is supplied via a dryer (104).

By opening the hand-operated valve (113) the CGR can be filled to the maximum required refrigeration load via the "P minimum" connexion. When a decrease of the capacity is wanted, cycle gas is blown off from the "P maximum" connexion to three sets each of two control bottles (110), (111) and (112) via the hand-operated valves (106), (107), (108) and (109). First valves (106) and (107) are opened. Valve (107) remains open until the increasing pressure in bottles (110) equals the decreasing pressure in the CGR. Valve (107) is then closed and bottles (111) and (112) are filled in a similar way if further decrease of the refrigerating load and thus of CGR cycle pressure is required.

An increase of the capacity is effected by discharging cycle gas from bottles (110), (111) and (112) to the "P minimum" connexion by closing valve (106) and opening valve (113) again. Valves (109), (108) and (107) are then opened and closed successively in the reverse sequence.

The contacts C and D of contact gauge (114) on the average cycle pressure, safeguard the machine against running at a cycle pressure too high or too low. These contacts will switch out the power supply to the driving electric motor. The cycle space of the CGR is also protected against too high a cycle pressure by means of relief valve (115).

The machine has to be started at the lowest possible cycle pressure. It is therefore advisable to reduce the cycle pressure in the manner described by using the compression ratio of the machine before stopping. With this system the refrigeration load can be manually and proportionally adjusted between 100 per

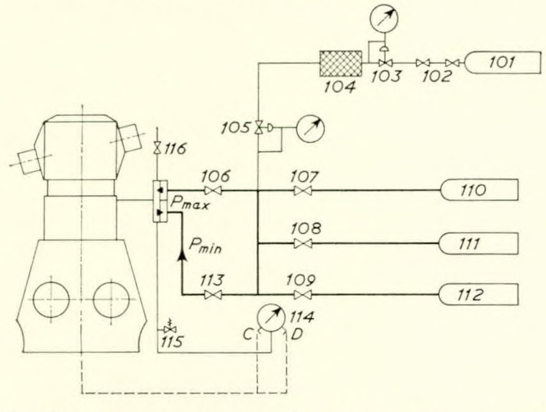


FIG. 5—*Manual adjustment of refrigeration capacity by means of CGR compression ratio*

cent and 35 per cent of full load capacity, without losing cycle gas by blowing-off to free atmosphere. If a still lower load and cycle pressure is wanted, cycle gas can be blown off by opening valve (116) to free atmosphere.

This basic system for manual adjustment of the refrigerating load can easily be modified into a complete automatic control system as shown in Fig. 6. In this example the refrigeration load and, thus, the supply or discharge of cycle gas, is governed by a pressure control (PC 120) on the gas to be liquefied by means of solenoid or pneumatic valves (A 106) and (A 113). This (PC 120) opens valve (A 113) and closes valve (A 106), when the pressure of the gas increases. The refrigeration capacity, therefore, has also to be increased by a supply of cycle gas. With decreasing pressure of the gas to be condensed, the pressure control carries out the reverse action.

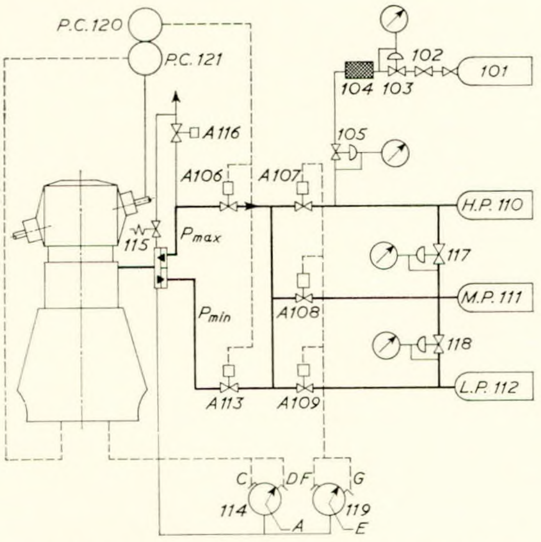


FIG. 6—*Automatic control of refrigeration capacity by means of CGR compression ratio*

The choice of which set of control bottles (110), (111) or (112) is to be connected with the supply or discharge lines of the machine is dependent on the cycle pressure and will therefore be controlled by contact gauge (119) on the average cycle pressure. This contact gauge (119) provides, via valves (A 107), (A 108) and (A 109), that the CGR will be connected in the preset sequence with the "high-pressure" bottles (110), the "medium-pressure" bottles (111) or the "low-pressure" bottles (112), when respectively high, medium or low cycle pressure prevails in the machine.

The pressure differential between the three sets of control bottles is maintained by means of the reducing valves (117) and (118). Usually an additional control (PC 121) is provided to switch the CGR off completely should the lowest refrigeration load to be achieved with this control system (35 per cent of full load) exceed the capacity required to maintain a set minimum pressure of the gas to be liquefied. When the pressure of the gas rises above this pre-set minimum value, the same control (PC 121) will start the CGR up again.

A completely different control system, in which a separate refrigerant gas compressor is applied instead of using the compression ratio of the CGR, is shown in Fig. 7. This system is normally used when helium is the refrigerant gas and no losses due to blowing-off to the free atmosphere can be accepted. Again the cycle gas originates from a set of high pressure bottles (201) and is supplied via reducing valves (203) and (205) and dryer (204). The set point of reducing valve (205) determines the minimum cycle pressure, pertaining to the required maximum load. By opening the hand operated valve (213) the CGR will be filled to the maximum load via the "P minimum" connexion. When a decrease in capacity is wanted, cycle gas is blown off via the hand-operated valve (206) through the compressor (209) to the control bottle (210) until the maximum cycle pressure equals the pressure in the control bottle (210). After this the compressor (209) can be started up to pump the remaining gas content into the bottle (210). Thus the CGR can be emptied completely without blow-off of refrigerant gas to free atmosphere, either for control purposes or for maintenance of the machine. The same compressor (209) can also be used to empty the set of supply bottles (201) completely and to store the gas in bottle (210). A manual adjustment of the refrigeration load between 100 per cent and 25 per cent of full load can be achieved with this system. Like the first manual control system described, this system too can be modified easily into an automatic system. In this case automatic control of valves (206) and (213) and automatic start-up and switch-off of compressor (209) by some form of input signal is necessary.

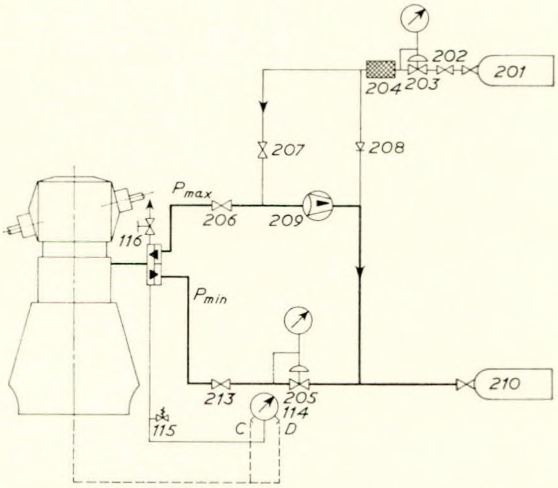


FIG. 7—*Manual adjustment of refrigeration capacity by means of separate cycle gas compressor*

THE RELIQUEFACTION OF BOIL-OFF FROM LIQUID GAS CARGOES

The most common marine application of the CGR to date, is the reliquefaction of the boil-off from a liquid gas cargo. However, the CGR can only be applied economically for the lower temperature ranges, i.e. between −80°C (112°F) down to −200°C (−328°F), rather limiting its application range in this field. In this temperature range, ethylene and natural gas (methane) with respective boiling temperatures of −104°C (−155°F) and −161°C (−257°F) are the only industrial gases with boiling and condensation temperatures at atmospheric pressure to be transported in bulk by ships. This does not mean that the CGR is not technically capable of reliquefying gases at higher condensation temperatures, such as ethane (−88°C, −126°F), propylene (−47°C, −52°F), propane (−42°C, −43°F), ammonia (−33°C, −27°F) and butane (−10°C) (+14°F), but these can be handled more economically in fairly simple compression/evaporation systems based on conventional freon or ammonia units, in one or more stages. Moreover, some of these gases can also be transported in pressurized cargo tanks at ambient temperatures instead of in refrigerated tanks at atmospheric pressure level. The choice of pressurized or refrigerated tanks is mainly dependent on the size of the carrier, but there is an increasing tendency to use refrigerated liquid gas carriers. Should ethylene or methane also have to be handled, the CGR equipment can be applied. Although the CGR would be especially suitable for the reliquefaction of methane, at present no methane carrier is equipped with such a plant. Methane is cheap and can therefore be used as fuel for the propulsion unit of the ship. The boil-off of the cargo tanks can be consumed in dual-fuel engines or in the boilers of steam propulsion plant in the carriers. Only a small methane reliquefaction plant, to balance the excess boil-off with the gas consumption of the propulsion plant, might still be considered for some projects.

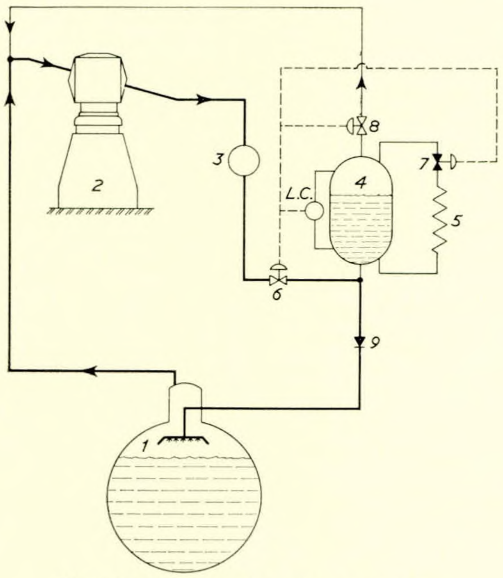


FIG. 8—*CGR reliquefaction plant*

Scheme of a CGR Reliquefaction Plant

A basic scheme is shown in Fig. 8. The boil-off vapour is drawn from the cargo tank (1) by condensation and suction action of CGR (2). The reliquefied vapour is discharged from the CGR by gravity and collected in the pressurizing container (4) via buffer container (3). After a certain height of liquid level is achieved in this pressurizing container, a pressure increase above the liquid in this container will be provided by means of the pressurizing coil (5), for which valves (6) and (8) have to be closed and valve (7) has to be opened. Some liquid gas is evaporated in the coil and as the vapour is fed back to the top of the pressurizing container, a pressure increase results. Through this the liquid is now transferred from the pressurizing container to the sprinkler system in the cargo tank until the pressurizing container is emptied and the valves (6) and (8) are opened and valve (7) is closed simultaneously again. The evaporation of liquid gas in coil (5) is caused by a heat flux from the surrounding ambient air or from an external hot water flow.

During the pressurizing period the condensate is stored for a short period in the buffer container (3). The pressurizing container is connected with the suction line via valve (8) to avoid pressurizing during the filling period. After the pressurizing period and closing valve (7) the liquid in the coil (5) is forced back into the pressurizing container by its own generated vapour, causing the pressurization to cease. Check valve (9) prevents liquid from the

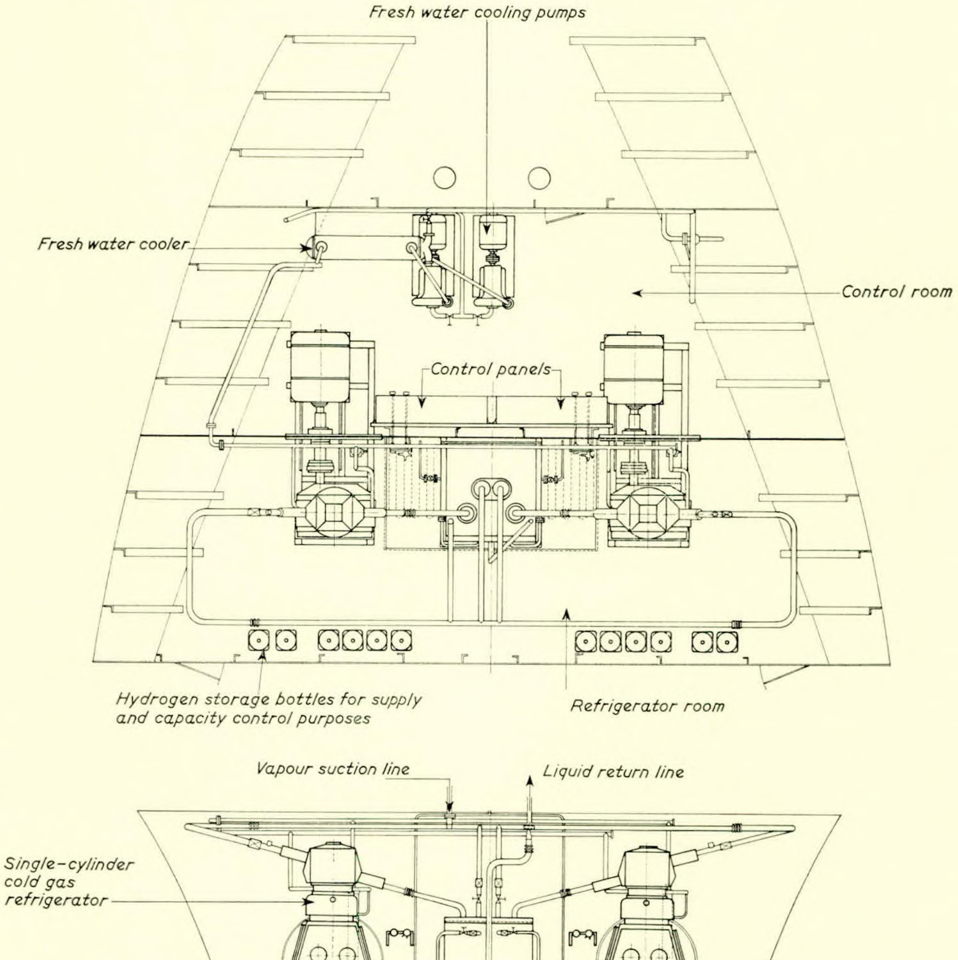


FIG. 9—*CGR reliquefaction plant*

supply lines to the sprinkler system flowing back into the pressurizing container.

As the equipment has to meet the rules of classification societies, the components have to be explosion-proof, so actuation of valves (6), (7) and (8) is controlled by a pneumatically amplified signal, proportional to the liquid level in the pressurizing container (4).

General Layout of a CGR Reliquefaction Plant

An example of the layout of a CGR ethylene reliquefaction plant, comprising two single cylinder units, is shown in Fig. 9. To meet the requirements of the classification societies, the plant is housed in the refrigerator room and a control room, separated by a bulkhead without any connecting openings. In the control room are housed all non-explosion proof plant components, for example electric motors and electric control, safeguarding and indicating devices. In the well-ventilated refrigerator room are housed the plant components containing explosive gases such as ethylene and the hydrogen cycle gas.

The driving shafts for the units in the refrigerator room are conducted through the bulkhead by means of gas-tight seals.

All valves in the hydrogen circuit as well as in the ethylene circuit, which are to be operated manually or automatically from the control room, are actuated by either a sealed shaft or a pneumatic signal line through the bulkhead. The information or control pressure signals from the hydrogen and ethylene circuit necessary for the operation in the control room, are transferred through the bulkhead either by an intermediate glycerine medium, e.g. sealed from the hydrogen by a metal bellows, or by a pneumatically transformed and amplified control-air line signal.

To meet classification societies' requirements, the plant illustrated has one single cylinder CGR in operation to liquefy the boil-off, while the other is a standby unit. For the same reason the plant is designed in such a way that with the exception of the pressurizing container itself there is a standby for each operating, moving or rotating component. Because it is very important to supply the coldest possible fresh cooling water to the units they are supplied from their own fresh water system, housed in the control room; the temperature level of cooling water from the propulsion engine system being too high for this duty.

CGR Reliquefaction Plants for Ethylene Carriers

Two reliquefaction plants, each comprising two single cylinder CGR units, have been delivered for the ethylene carriers m.v. *Teviot* and m.v. *Traquair* which transport liquid ethylene between the United Kingdom and the Netherlands. They made their first trips in August and December 1966 respectively.

The plants are in the bow compartments of the carriers. The refrigerating capacity of the units, operating with hydrogen as the cycle gas, is automatically controlled within a limited range by the ethylene cargo tank pressure using the compression ratio of the CGR itself.

For operation, without continuous attendance by the ships' engineers, the machinery is safeguarded by limitation of minimum and maximum hydrogen cycle pressure, power consumption of the units, maximum cooling water temperature, minimum cooling water flow, minimum lubricating oil pressure and minimum cargo tank pressure.

In the wheel house there are signal bulbs, indicating whether or not the units are running too low an ethylene cargo pressure, and automatic switchoff of the CGR should the cargo pressure drop below a set minimum. There is also an emergency stop button for the reliquefaction units and alarm devices, operating when the units are stopped by the safeguarding devices mounted in the control room.

One reliquefaction plant, comprising three single cylinder units, has been delivered for the ethylene carrier m.v. *Thales*. The vessel transports liquid ethylene from France to Sweden and made her first trip in July 1967.

This plant is erected in two rooms, separated by a gas-tight bulkhead, in the bow of the carrier. The refrigerating capacity of the units, operating with helium as the cycle gas, is controlled manually from the wheel house. The control system, based on the scheme with a separate cycle gas compressor, is used.

TABLE I—TECHNICAL DATA OF SINGLE-CYLINDER WERKSPOOR COLD GAS REFRIGERATOR (CGR) FOR RELIQUEFACTION OF BOIL-OFF GASES

Frequency of power supply to driving electric motor, Hz	50		60	
Running speed of CGR, rev/min	1500		1800	
Seawater temperature, °C	7	32	7	32
Average temperature in fresh cooling water system, °C	15	40	15	40
Refrigeration capacity while reliquefying: methane at −161°C, kW	18·0	17·2	20·75	19·7
ethylene at −104°C, kW	25·0	24·1	29·7	29·0
Power consumption (inclusive of electric motor efficiency) while reliquefying: methane at −161°C, kW	98	107	121	132
ethylene at −104°C, kW	69	81	87	101
Flow in fresh cooling water system while reliquefying: methane at −161°C, m^3/h	15·7	16·8	19·1	20·4
ethylene at −104°C, m^3/h	12·8	14·3	15·8	17·6

For manual operation from the bridge, the wheel house panel of the reliquefaction plant is provided with start and stop buttons for the units and the cycle gas compressors with appropriate indicator lights, indication of consumed power and cycle pressure of the units and signal bulbs for the safeguarding devices limiting maximum consumed power, minimum and maximum helium cycle pressure, minimum lubricating oil pressure, maximum cooling water temperature, minimum cooling water flow and thermic overload of electric motors.

PRODUCTION OF INERT GAS BY SEPARATION OF NITROGEN FROM AIR

Inert gas systems have already been used in tankers for a number of years, the main purpose being the reduction of the oxygen content of the atmosphere above explosive or oxygen sensitive cargoes.

Until now all inert-gas systems used air and a liquid fuel as basic materials. The burning of fuel with air results in a combustion product containing mainly nitrogen, carbon dioxide and water vapour and traces of oxygen, carbon monoxide, sulphur dioxide and other contaminants. The volume of the contaminants is dependent on the composition of the fuel, completeness of combustion and the ratio of the original fuel-air mixture.

The simple inert gas systems use the flue gases from the steam boilers, while others are based on the combustion of Diesel engine fuel in a separate burner. The low oxygen content of the atmosphere in the cargo tank will also reduce oxidation of the cargo as well as of tank wall materials, resulting in less corrosion of the latter. However, the inert atmosphere contains carbon dioxide, sulphur dioxide and water vapour, by which corrosion could possibly be increased. To reduce this corrosion, the more advanced inert gas systems also comprise equipment for sulphur dioxide removal and dehumidification, while sometimes white spirit without sulphur content is used as fuel. However, even the most advanced systems, based on fuel burning, will produce an inert gas containing nitrogen, carbon dioxide and traces of moisture. It can be well imagined that the carbon dioxide contents will contaminate some petrochemicals, aromatics and other special products. A solution could be an inert gas system, based on the principle of an air separation plant. Then no fuel is involved in the inert gas product and an absolutely dry nitrogen gas with an impurity of less than 50 ppm can be supplied.

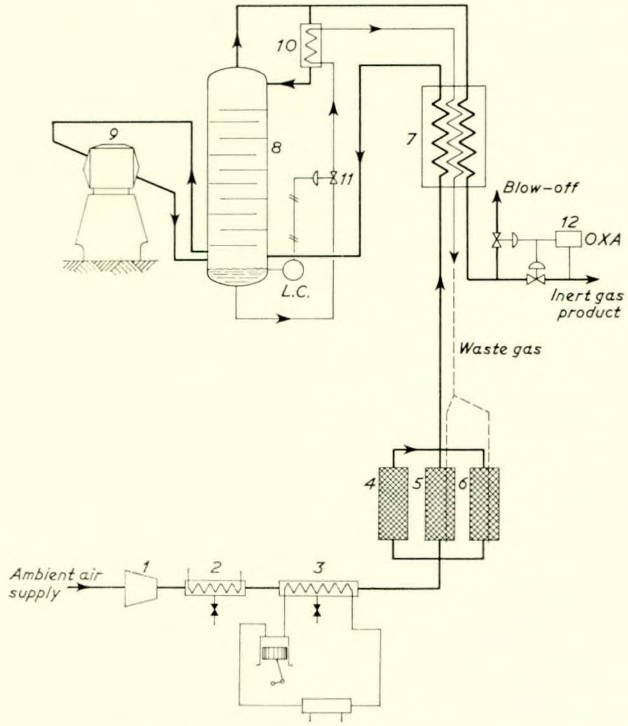


FIG. 10—*CGR inert gas plant*

Scheme of a CGR Inert Gas Plant

The essential scheme is shown in Fig. 10. Atmospheric air is compressed by the oil-free compressor (1) and is then successively cooled down to approximately 0°C (32°F) in the water-cooled aftercooler (2) and freon refrigerated cooler (3), where the separated water condensate is drained. In one of the three absorbers (4), (5) or (6) the air is further purified from carbon dioxide and rest water contents down to a dewpoint of at least −70°C (−94°F). In the counterflow heat exchanger (7) the air flow is then cooled down to about condensation temperature by the nitrogen product flow and the oxygen-enriched waste gas flow, both leaving the plant. Further, the air is supplied to the bottom of the air separation column (8). One part of this air flow is sucked in by the CGR (9) and liquefied, after which this liquid returns to the bottom of the column. The other part of the supplied air rises as a vapour flow in the column in counterflow with a downcoming liquid stream. This rising vapour flow will be rectified from air at the bottom of the column to pure nitrogen at the top, while simultaneously the downcoming liquid changes from pure nitrogen at the top of the column into oxygen-enriched air at the bottom. The downcoming liquid stream is caused by the evaporator-condenser (10). At the condenser side nitrogen will be liquefied at high pressure, while at the evaporator side oxygen-enriched waste gas evaporates at near atmospheric pressure. The liquid waste gas is supplied from the bottom of column to the evaporator-condenser via expansion valve (11), controlled by the level control (LC) at the bottom of the column.

The pure nitrogen gas product is discharged from the top of the column at high pressure and supplied to the consumer via the counterflow heat exchanger (7) and controlled by the oxygen content analyser (12). When the nitrogen purity does not meet the required value, the nitrogen will be blown off instead of supplied to the consumer.

The dry low-pressure waste gas leaving the counterflow heat exchanger is still used to regenerate the saturated absorbers. The non-operating absorbers are successively regenerated by a heated waste gas flow and cooled down again to operation temperature by a non-heated waste gas flow. The switching over of the absorbers to their following cycle stage is automatically and time controlled.

An inconvenience is that the plant has to be cooled down before inert gas generation can be started-up. The cooling down takes several hours of CGR operation, but can be started while still at sea, before the cargo is discharged in harbour by the cargo pumps and topping up by inert gas is required.

TABLE II—TECHNICAL DATA OF INERT GAS PLANT BASED ON A SINGLE CYLINDER WERKSPOOR COLD GAS REFRIGERATOR

Frequency of power supply to driving electric motors, Hz	50		60	
Running speed of CGR, rev/min	1500		1800	
Sea water temperature, °C	7	32	7	32
Average temperature in fresh cooling water system, °C	15	40	15	40
Temperature of ambient air, °C	7	32	7	32
Production capacity for gaseous nitrogen, nm³/h	1230	1170	1415	1340
Maximum nitrogen impurity, ppm	50	50	50	50
Dewpoint for moisture and carbon dioxide in nitrogen product, °C	−183	−183	−183	−183
Pressure of nitrogen product, atm	3·5	3·5	3·5	3·5
Temperature of nitrogen product, °C	−5	−5	−5	−5
Capacity of oil-free air compressor, nm³/h	3160	3000	3640	3440
Required refrigeration capacity of air-pre-cooling Freon plant at 0°C, kcal/h	29 600	74 000	34 000	85 000
Power consumption (inclusive of electric motor efficiencies):				
oil-free compressor, kW	244	231	280	265
Freon plant, kW	3	24	3·5	27·5
Single cylinder CGR, kW	119	128	147	156
Heating device for absorber regeneration, kW	8·5	8	9·5	9
Total, kW	374·5	391	440	457·5
Flow in fresh cooling water system, m³/h	44	52	52	60

PRODUCTION OF LIQUID OXYGEN BY AIR SEPARATION

Oxygen production plants in ships are, as far as is known, only applied for military purposes. Because of the confidential nature of this field not much is known about the exact purposes of the produced oxygen, but it is known that aircraft carriers use oxygen generators for the production of respiration oxygen, to be used by the aircrews. Also oxygen is produced on board submarines for respiration purposes, as well as for torpedo propulsion units.

Because oxygen consumption is normally periodic and production preferably continuous, the oxygen produced has to be stored. Thus it is obvious that for a ship oxygen generating unit a liquid oxygen product will be preferred, because of its small storage volume.

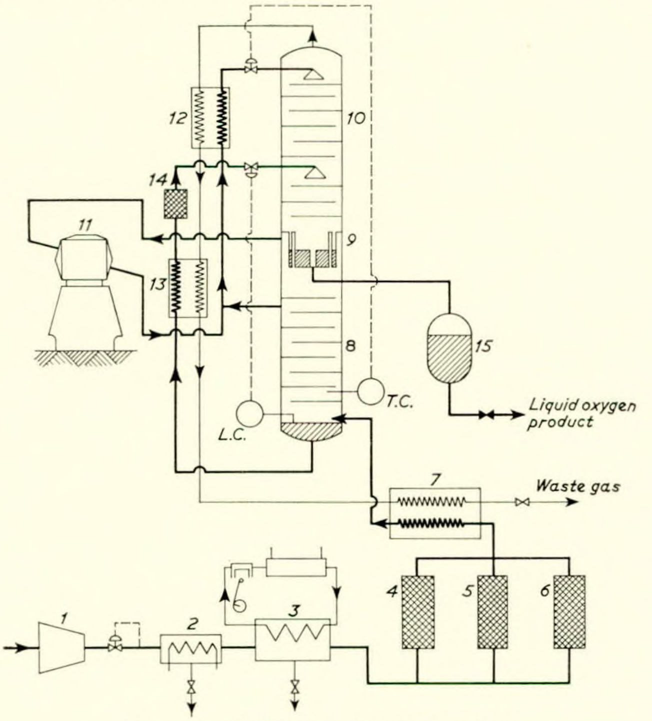


FIG. 11—*CGR liquid oxygen plant*

Scheme of a CGR Liquid Oxygen Plant

Fig. 11 shows one of many possible air separation plant schemes for oxygen production. The scheme chosen here for shipboard use, has a reasonable power consumption but is still not too complicated.

The compression of the intake air, its drying and its cooling down to about condensation temperature in counterflow with the waste gas to be blown off, takes place in the same way as with the inert gas plant.

After the counterflow heat exchanger (7) the compressed air is supplied to the H.P. rectification column (8). Here the air rises as a vapour flow in counterflow with downcoming liquid, by which the vapour will be rectified to pure nitrogen at the top of the column and the liquid to oxygen-enriched air at the bottom.

The downcoming liquid in the H.P. column is provided by the evaporator-condenser (9), separating the upper L.P. column (10) from the lower H.P. column (8). The evaporator-condenser liquefies nitrogen in the H.P. column by the evaporation of pure oxygen on the L.P. column side, by which also a rising oxygen vapour flow in the L.P. column is provided.

The refrigeration capacity, to provide the liquid flows in both columns as well as the liquid oxygen product, is generated by the CGR (11) that liquefies nitrogen gas from the top of the H.P column. To realize the necessary downcoming liquid flow in the L.P. column, liquid nitrogen is supplied to the top of the L.P column from the top of the H.P. column and from the CGR, as well as oxygen-enriched liquid air supplied to a lower section of the L.P. column from the bottom of the H.P. column. These liquid re-flux flows are supplied to the L.P. column respectively via subcoolers (12) and (13), wherein the liquid flows are subcooled by waste gas, leaving the top of the L.P. column. In addition the oxygen-enriched air reflux also passes an acethylene filter (14). Both re-flux flows are supplied via expansion valves controlled respectively by the liquid level (LC) and the temperature (TC) at the bottom of the H.P. column. The downwards liquid stream in the L.P. column is rectified into pure liquid oxygen at the bottom of the L.P. column by the rising vapour flow.

The liquid oxygen product will be drained from the L.P. column side of evaporator-condenser and stored in container (15). From this storage container the oxygen can be prepared for consumption, either by pressurized evaporation for direct use in gaseous stage, or by distributing liquid oxygen into smaller containers for use elsewhere.

TABLE III—TECHNICAL DATA OF LIQUID OXYGEN PLANT BASED ON A SINGLE CYLINDER WERKSPOOR COLD GAS REFRIGERATOR

Frequency of power supply to driving electric motor, Hz	50		60	
Running speed of CGR, rev/min	1500		1800	
Sea water temperature, °C	7	32	7	32
Average temperature in fresh cooling water system, °C	15	40	15	40
Temperature of ambient air, °C	7	32	7	32
Production capacity for liquid oxygen, kg/h	138	128	154	150
nm^3/h	97	90	108	105
Oxygen purity, per cent	99·5	99·5	99·5	99·5
Dewpoint for moisture and carbon-dioxide in oxygen product, °C	−180	−180	−180	−180
Pressure of oxygen product, ata	1·1	1·1	1·1	1·1
Capacity of oil-free air compressor, nm^3/h	518	480	579	563
Refrigeration capacity of air-precooling Freon plant at 0°C, kcal/h	2200	8650	2460	10144
Power consumption (inclusive of electric motor efficiency):				
oil-free compressor, kW	49	51·6	54·7	60·2
Freon plant, kW	0·5	3·7	0·5	4·3
Single-cylinder CGR, kW	112·5	120·5	137·1	146·2
heating device for absorber regeneration, kW	15	15	16	16
Total, kW	177·0	190·8	208·3	226·7
Flow in fresh cooling water system, m^3/h	18	21	20	25

PRODUCTION OF LIQUID GAS FOR SUPPLY TO REFRIGERATED CONTAINERS

Liquid nitrogen refrigerated containers for the transport of deep frozen or cooled perishable goods have been in use for some time. For individual containers of this type, advantages that can be claimed with respect to individual mechanical refrigeration are: simple, unattended operation; perfect control between narrow limits of temperature in the container; minimal maintenance; short container precooling time and almost non-existent desiccation of the product with the accompanying thawing of the cold evaporator surfaces provided with mechanical systems.

However, these advantages will only be realized so long as the liquid nitrogen storage bottles of the containers still contain liquid gas or if a sufficient supply of liquid gas to these bottles at any moment can be guaranteed. Because the storage capacity of the liquid nitrogen bottles in the containers is limited and until now their filling has been at shore facilities, liquid nitrogen refrigerated containers are only used on shipboard for regular, short range services.

A solution to the problem of providing a reliable supply of liquid gas to the containers on board, could be the on board production and distribution to the container bottles of liquid gas.

Scheme of a CGR Plant for Supply of Liquid Refrigerant Gas to Cargo Containers

Nowadays liquid nitrogen for container refrigeration is supplied by gas producers from large air separation plants on shore. These plants, however, are generally meant for oxygen production in the first place, while gaseous impure nitrogen is blown off as waste gas. As a matter of fact liquefied waste nitrogen is supplied should liquid refrigerant gas for container transport be required. For the liquid gas production unit on board, liquid air can be chosen as the end product as well as liquid nitrogen. If only the production unit itself were to be considered, liquid air would be preferable, because a liquid air unit is less complicated than a liquid nitrogen unit. Figs. 12 and 13 respectively show schemes for a liquid air and a liquid nitrogen plant.

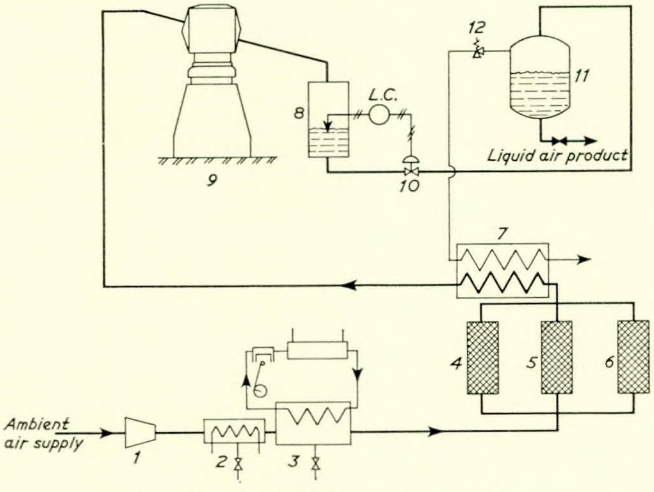


FIG. 12—*CGR liquid air plant*

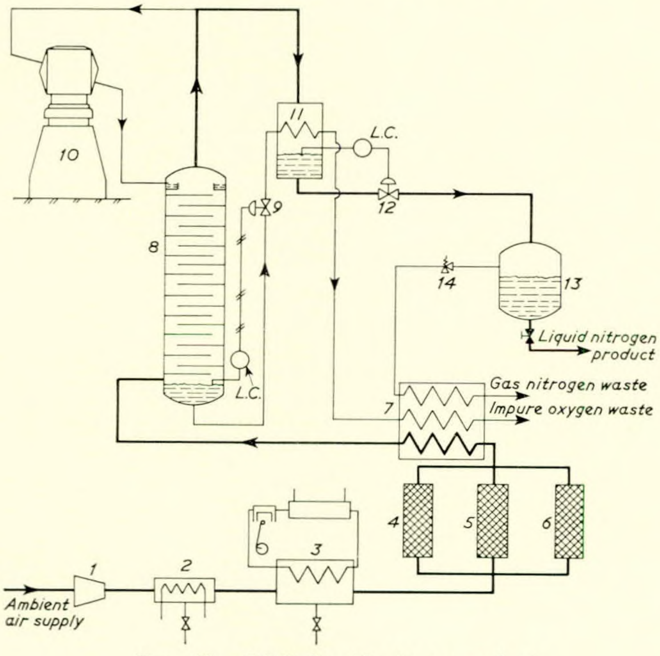


FIG. 13—*CGR liquid nitrogen plant*

The air, taken in from the ambient atmosphere, is compressed, pre-cooled, dried in absorbers and cooled down in counterflow with the waste gases, as in the inert gas plant scheme. The liquid air collected in vessel (8) and also the liquid nitrogen collected in the evaporator-condenser (11) are both produced under pressure and are then discharged into the atmospheric storage vessels (11) and (13) via expansion valves (10) and (12). The flash gas generated here is blown off as waste gas to free atmosphere via the counterflow heat exchanger (7).

From the storage vessels the liquid gas products can be distributed to the bottles in the containers when required.

The dimensions of the storage vessel determine the flexibility of the use of full load capacity of the liquid gas plant, e.g. this vessel makes it possible to produce liquid for containers expected to arrive but not yet on board. From the user's point of view there may be some preferences from either liquid air or nitrogen. Nitrogen can present a danger of suffocation, if the container is entered without necessary precautions being taken. On the other hand, nitrogen seems to have a good influence on the quality of some cooled perishables, because the metabolism of living product will be retarded by an inert gas atmosphere, though this advantage is not valid for deep frozen products. Another disadvantage is discoloration of blood rich products and a progressive growth of very detrimental bacteria, propagating in an oxygen-starved atmosphere.

TABLE IV—TECHNICAL DATA OF LIQUID AIR AND OF LIQUID NITROGEN PLANT BASED ON A SINGLE CYLINDER WERKSPOOR COLD GAS REFRIGERATOR

Frequency of power supply to driving electric motor, Hz	50		60	
Running speed of CGR, rev/min	1500		1800	
Sea water temperature, °C	7	32	7	32
Average fresh cooling water temperature, °C	15	40	15	40
Temperature of ambient air, °C	7	32	7	32
Liquid air unit:				
Production capacity of liquid air, kg/h	129	119	144	140
dm³/h	148	136	165	160
Pressure of liquid air product, ata	1·1	1·1	1·1	1·1
Quantity of air supplied by oil-free compressor, kg/h	157	145	175	171
nm³/h	122	113	136	132
Refrigeration capacity of air-precooling Freon plant at 0°C, kcal/h	549	2270	611	2662
Power consumption, inclusive of electric motor efficiency:				
oil-free compressor, kW	9·9	10·5	11·1	12·3
Freon plant, kW	0·2	1·1	0·2	1·2
Single-cylinder CGR, kW	112·6	120·4	137·3	146·2
heating device for absorber regeneration, kW	4·5	4·5	5·0	5·0
Total, kW	127·2	136·5	153·6	164·7
Flow in fresh cooling water system, m³/h	14	15	18	18

Liquid nitrogen unit:				
Production capacity of liquid nitrogen, kg/h	126	118	141	136
dm^3/h	156	146	174	168
Pressure of liquid nitrogen product, ata	1	1	1	1
Nitrogen purity, per cent	99·5	99·5	99·5	99·5
Quantity of air supplied by oil-free compressor, kg/h	290	272	324	314
nm^3/h	225	211	251	244
Refrigeration capacity of air-precooling Freon plant at 0°C, kcal/h	1015	4244	1133	4899
Power consumption, inclusive of electric motor efficiences:				
oil-free compressor, kW	17·9	19	19·9	21·9
Freon plant, kW	0·3	1·9	0·3	2·2
Single-cylinder CGR, kW	112·8	123·1	139·8	149·9
heating device for absorber regeneration, kW	6	6	7	7
Total kW	137	150	167	181
Flow in fresh cooling water system, m^3/h	15	26	28	31

Liquid air is sometimes said to be dangerous because of possible oxygen-enrichment by slow evaporation, resulting in escape of nitrogen-enriched vapour from the storage vessel or from the container liquid gas bottles. However, this danger is mostly exaggerated and can eventually be prevented by technical means.

Capacity of Liquid Gas Plant, Required for Container Refrigeration

Besides the outputs of the liquid air and the liquid nitrogen production units, it is of interest to know roughly what unit output would be required for a given number of refrigerated containers on board.

Tables V and VI show the calculation of the liquid nitrogen consumption of a 20-ft container under different operation conditions. It is assumed that the 20-ft container, with standard outer dimensions of 20 ft by 8 ft by 8 ft, is equipped with the usual four liquid gas bottles of 210 litres liquid content each.

The liquid nitrogen consumption per container on board is less than on shore, because, assuming transportation in the ship's hold, the extra allowance for heat leak through the container insulation due to sun radiation can be omitted.

Furthermore, there could be an additional advantage of container transport in the hold. If deep-frozen goods and all refrigerated containers are loaded in the same hold compartment, it can be postulated that, by blowing off consumed gas with a temperature of −20°C (−4°F) from the containers into the hold compartment, the temperature of the air surrounding the containers will drop. Thus the liquid gas consumption will decrease too. This can probably be further developed technically to prevent convective movement of the air around the containers. However, shipping companies will find it difficult to achieve the stowage of all refrigerated containers in one and the same hold compartment, because of the loading sequence of the containers, normally unknown. Should liquid air be used instead of liquid nitrogen, the consumption figures in dm^3/h for liquid nitrogen have to be multiplied by a factor of 0·935 to convert those into container consumption figures for liquid air.

The refrigeration capacity in kcal/dm^3 of liquid air is greater than for liquid nitrogen. This also means that the operation time with the 840 dm^3 liquid gas, stored in the container bottles, is greater for liquid air than for liquid nitrogen by a factor of 1·07.

The maximum refrigeration time of the liquid nitrogen, to be stored in the four container bottles, is between 53 and 104 hours for operation on shore and between 57 and 125 hours for operation on board. So the container bottles have to be re-

TABLE V—LIQUID NITROGEN CONSUMPTION OF A 20-FT CONTAINER FOR TRANSPORT OF DEEP-FROZEN CARGO

Average ambient temperature during 24 hours a day, dependent on season and area in the world (t_o), °C	25	15
Cargo temperature (t_i), °C	−20	−20
Heat transfer coefficient of insulation (k), kcal/m^2.h.°C	0·20	0·20
Outer surface of container, (F), m^2	71	71
Heat leakage through insulation /$k.F.$ ($t_o - t_i$), kcal/h	640	497
Extra allowance for heat leakage due to sun radiation 20 per cent of $k.F.$ ($t_o - t_i$), kcal/h	128	100
Total required refrigeration capacity, kcal/h	768	597
Refrigeration capacity of liquid nitrogen at atmospheric pressure, while heating up to −20°C, kcal/dm^3	74	74
Liquid nitrogen consumption of container (on shore) dm^3/h	10·4	8·1
(on board dm^3/h	8·7	6·7
Operation time of container, equipped with 840 dm^3 liquid nitrogen bottle capacity (on shore), h	80	104
(on board), h	97	125

TABLE VI—LIQUID NITROGEN CONSUMPTION OF A 20-FT CONTAINER FOR TRANSPORT OF REFRIGERATED CARGO WITH ITS OWN HEAT REGENERATION

Average ambient temperature during 24 hours a day dependent on season and area in the world (t_o), °C	25	15
Cargo temperature (t_i), °C	0	0
Heat transfer coefficient of insulation (k), kcal/m^2.h.°C	0·20	0·20
Outer surface of container (F), m^2	71	71
Heat leakage through insulation/$k.F.$ ($t_o - t_i$), kcal/h	356	213
Extra allowance for heat leakage due to sun radiation 20 per cent of $k.F.$ ($t_o - t_i$), kcal/h	71	43
Load capacity of container, tons	10	10
Assumed maximum heat generation by metabolism of cargo, dependent on product, quality of product and product temperature, kcal/h. tons	80	80
Heat generation by cargo, kcal/h	800	800
Total required refrigeration capacity, kcal/h	1227	1056
Refrigeration capacity of liquid nitrogen at atmospheric pressure, while heating up to 0°C, kcal/dm^3	78	78
Liquid nitrogen consumption of container (on shore), dm^3/h	15·7	13·6
(on board), dm^3/h	14·8	13·0
Operation time of container, equipped with 840 dm^3 liquid nitrogen bottle capacity (on shore), h	53	62
(on board), h	57	65

supplied with liquid nitrogen after a refrigeration period roughly between two and five days, depending on cargo and conditions.

The figures for continuous liquid nitrogen consumption on board are 6·7 to 14·8 dm^3/h. Bearing in mind that the output of a liquid nitrogen unit, based on a single cylinder CGR, is between 146 and 174 dm^3/h; such a unit is obviously capable of a continuous supply of liquid nitrogen to from 10 to 26 containers 20 ft long. However, taking into account that the containers will not be continuously on board and that, by means of the large liquid nitrogen storage vessel coupled to the production unit, liquid nitrogen can be pre-produced, it is obvious that the number of containers to be supplied by each single cylinder unit is quite flexible. The capacity of the production unit and of the storage vessel will have to be adapted to the operational conditions, which vary for each project.

For a rough estimate of the liquid gas consumption of 40-ft containers, all consumption figures for the 20-ft containers have to be doubled. The liquid gas capacity to be stored in the 40-ft container has also to be increased to provide a similar length of refrigeration period with one liquid gas filling. For this purpose a big quadrangular vacuum-insulated liquid gas container of 1500 litres capacity can be fitted in the 40-ft container and replaces the four separate vacuum-insulated bottles of the 20-ft container.

All consumption and production figures mentioned must be considered as rough estimates. Certain factors have not been considered, such as insulation losses from the liquid gas storage vessel and from the pipe network for liquid gas distribution from the storage vessels to the containers stowed in the holds.

PRODUCTION OF LIQUID GAS FOR CRYOGENIC SHOCK-FREEZING OF VALUABLE FISHERY PRODUCTS

Conventional freezing plants, i.e. plate freezers and airblast freezing tunnels, for which the refrigeration capacity is generated in ammonia or freon compression-evaporation units, have been in use on board fishing vessels for some time. Large quantities of fish are landed only in a cooled condition, i.e. in sharp ice, and are frozen on shore.

A new method of preservation of food products is cryogenic freezing by means of liquid gas, to be evaporated by direct or indirect contact with the food product. This shock freezing is used quite extensively in the U.S.A. for on-shore freezing of shell fish. Only valuable shell fish is shock frozen, because these types of fish must be of the highest possible quality, are hard to freeze with the slower freezing speeds of conventional equipment and are able to bear higher preservation costs in relation to market prices. Cryogenic freezing is sometimes also preferred for reasons of easier processing. In the cryogenic freezing plants as at present operating on shore, liquid nitrogen is supplied to the freezing plant site by a gas producer. Here the guaranteed supply of nitrogen and an acceptable low nitrogen price depend on the distance and quality of the transport links between the freezing plant and the gas producer's site. A solution for the extension of the applicability of cryogenic freezing is offered by a self-supporting small air liquefaction plant, which can be operated by the food processor himself.

Although in the first place the cryogenic freezing plant is thought to operate on shore, this cryogenic freezing of shell fish is still considered as a possible marine application of the CGR, because the fishing itself and the processing of fish on shore are connected to a great extent.

The operation of this advanced shock-freezing equipment takes place on shore, because it requires an investment which can only be economically justified if a constant and full load operation can be realized. To meet this condition the freezing plant cannot depend on the catch of one fishing trawler, but has to process those of several vessels. Yet its use on board a factory ship dealing with the hauls of several trawlers, can be foreseen for the future, again creating a purely marine CGR-application.

Production of Liquid Gas on Site of Shock-freezing Plant

For the liquid gas production unit on the food processor's site, or on board the fish factory ship, liquid air will be preferred as the end product, unlike the cryogenic freezing plants, supplied with liquid nitrogen by the gas producers. There the liquid nitrogen can be considered as liquefied waste gas from the gas producer's oxygen plant and is even easier to supply than liquid air. For the small food processor's liquid gas unit, though separation of air into nitrogen and oxygen waste gas is possible, it would make the small unit unnecessarily complicated and expensive.

The advantage of nitrogen in being inert, is doubtful in connexion with the shock freezing process. The influence on food products of nitrogen as an inert medium, or of air as an oxidizing medium, can generally be reckoned as negligible, because of the very short time in the shock-freezing tunnel.

The CGR liquid air production unit shown in Fig. 12 can be used in the same manner for freezing purposes.

The Process in the Cryogenic Freezing Tunnel

The freezing process in the freezing tunnel of the author's company is shown in Fig. 14.

The food product is transported through the various sections of the insulated tunnel by an endless wire mesh conveyor belt. In each section, from above as well as through the belt from below, turbulent air, generated by a blower and air distribution system in each section, flows over the product. The liquid air is supplied to the section close to the exit from the tunnel. A temperature controller maintains the temperature of this section at a constant adjusted value by means of the liquid air supply. The liquid air is evaporated in the circulating airflow of the section blower in question, after which this evaporated air is supplied to and mixed with the blower airflow. Thus the liquid air never contacts the product itself and the lowest operating temperature of the airflow coming into contact with the food product is adjustable between −194°C (−317°F) and any higher temperature, if required.

The evaporated air is discharged from the tunnel entrance. Thus, in counterflow with the product, this flow of evaporated air passes all sections between the liquid air supply section and the product entrance section, thereby absorbing heat from the food product. This counterflow principle is used not only to gain

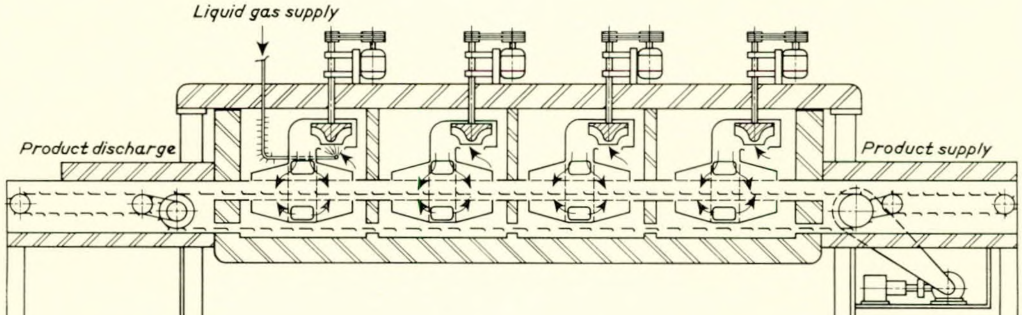


FIG. 14—*Schematic cross-section of Stork-Werkspoor cryogenic freezing tunnel*

efficiency, but also to obtain a decrease in material tensions in the product during the freezing process.

To adjust to the various required freezing speeds of the different products, the temperature of each section, the quantity of heat to be transferred per section and the product process time in the tunnel can be varied, as can the blower speed per section and the speed of the conveyor belt. Good accessibility to the interior of the tunnel for cleaning purposes is ensured, as the insulated vertical walls and the bottom of the tunnel can be removed as one unit. Improvements to the quality of shock frozen products as described are: less cellular breakdown during freezing and consequently less drip loss after thawing, less desiccation, less separation of fat and less protein denaturalization, by which preservation of the product is improved, to a degree dependent on the type of product.

Advantages of the cryogenic freezing process especially important for freezing on board ship are: less manpower is required by the continuous process, there is a shorter process time, little space is required and the tunnel capacity is flexible because of the heavy loading possible and the ability to preproduce liquid air during tunnel down time.

Freezing Capacity of Single Cylinder Werkspoor CGR Liquid Air Plant

The freezing capacity of a CGR liquid air plant, liquid air storage vessel and cryogenic freezing tunnel, is dependent on the net refrigeration requirement of each product and on the efficiency of the heat exchange in the tunnel. The net refrigeration capacity to freeze shellfish, such as scallops, shrimps, lobsters, oysters and crabs, or fish fingers and fillets from an initial temperature of 20°C (68°F) down to −20°C (−4°F) is in the range of 89 to 98 kcal per product kilogramme. Estimated with a blow-off temperature of the consumed gas from the tunnel of −20°C (−4°F) and taking into account losses due to heat leakage through the tunnel insulation and a refrigeration loss due to cooling down of the tunnel during start up, the practical requirements will be 1·1 to 1·2 kg liquid air/kg product for a continuous tunnel operation period of at least eight hours.

Thus a single cylinder CGR liquid air plant is capable of freezing continuously about 100 to 125 kg fish product per hour (see Table IV). When the liquid air plant is provided with sufficient storage vessel capacity, the tunnel can be operated periodically and the liquid air unit continuously. For example, the liquid air produced in 24 hours can be consumed during eight hours of tunnel freezing. Thus a single cylinder unit can supply liquid air for a tunnel with a throughput of about 300 to 380 kg fish product per hour.

CONCLUSION

The use of low temperatures and consequently the marine applications of cold gas refrigerators, must have their origin in an economic need. Therefore the economics of CGR use are most important and will be the main factor in any decision. However, space does not permit their discussion here. Furthermore such factors as depreciation, loss of interest, anticipated operation time, the need for additional investment to provide the required power and cooling water, energy and cooling water costs on board, have to be known to calculate the economics of CGR use and to compare them with possible alternative solutions. Because these factors vary for each project and are dependent on the attitude of the shipping companies, an economic estimate has been omitted. Instead, to introduce the subject of CGR marine applications, an attempt has been made to describe some technical and engineering aspects of present as well as of possible future marine applications of Stirling refrigerators.

Discussion

MR. M. Z. NAVAZ (Associate member) said the paper was an excellent one dealing with the marine application of Stirling cycle refrigerators.

The advantages of that type of refrigerator appeared to be:

a) compactness for shipboard use;
b) the very small refrigerant flow quantity, so that only small quantities of reserves need be carried;
c) low temperature liquefied gases, boil off vapours could be contained within the ship's system, thus helping to maintain greater standards of safety by preventing accidental ignition of boil off vapour at outlets due to static electricity, or other means—such ignition had occurred on LNG ships;
d) the boil off cargo vapour was not subjected to high temperature thermal shocks, thus avoiding the risk of auto ignition;
e) a suitable secondary refrigerant might be used for cargo cooling within the cargo tanks.

This refrigerator was a new type of mechanical heat sink with nearly all the auxiliaries contained as a unit around the compressor, as if it were an integral part of it, thus probably providing a very high refrigeration capacity as a low temperature heat sink unit per floor area of plant machinery. Mr. Navaz said that that would be true in terms of weight ratios also and that it would be interesting to know the comparative costs (from an operation and installation point of view) with conventional refrigeration units making use of the change of state process by means of the Joule Thompson effect; the study being based on refrigeration effect against product temperature at, say, 0°C, and below minus 50°C.

Lloyd's Register of Shipping has given general approval for two types of Stirling cycle refrigerator, both working on the same principle, except for the drive mechanism, for use with helium as the refrigerant. The dry sump of the compressor has been approved for use with hydrogen as a refrigerant, but with additional safeguards called for:

1) a crankcase non-return relief valve should be provided and located as high as possible in the crankcase body fitted with a pipe leading to atmosphere outside the compressor compartment; the outlet end of the pipe fitted with a gauze cover;
2) a small quantity of inert gas should be constantly percolated through the crankcase;
3) a minimum of two lubricating oil pumps should be provided, one to be independently driven;
4) means should be provided to prevent operation of plant unless minimum lubricating oil pressure was maintained;
5) adequate alarm devices should be provided for the safe running of the plant on the cooling water, lubricating oil, refrigerant and heat exchanger side of the plant;
6) a one hundred per cent separation, by means of a gas-tight bulkhead, should be provided between the motor and the gas compressor.
7) cooling water pumps should be located in the motor room, provided the fresh water make up header tank was totally enclosed with a vent pipe to the atmosphere outside the compartment, or for the header tank to be located in the open.

All that has been discussed with the manufacturers and agreed to a short while previously. The first five points provided a safeguard against leakage of hydrogen into the crankcase and the development of a hot spot, and the remainder took account of possible gas leaks into the compartment and cooling water system.

Illumination by means of fittings in the compressor room was not permissible because there was no type of fitting certified flame-proof for hydrogen.

That would mean fitting gas-tight glass portholes with the lights situated outside the compartment, or the light fitting would have to be gas tight in the compartment.

Mr. Navaz asked the authors what method they adopted to leak test the refrigerant lines with hydrogen was used.

Figs. 15 to 17 were given to show the possible scope.

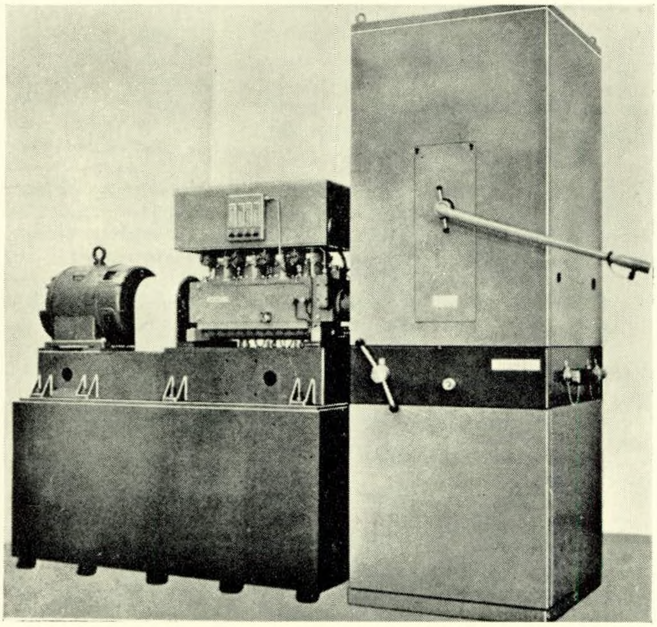


FIG. 15

Fig. 15 showed a Stirling refrigerator used for manufacturing nitrogen for shipboard use as an inert gas. The compressor was not the same as that described by the authors, but the basic process was very similar.

Fig. 16 showed a shipboard installation, illustrating the authors' compressor in position, being used for ethylene production. The important point was that the crankcase relief valve was located at the top, the pipe being led outside to the atmosphere. Mr. Navaz drew attention to the pump, and stressed the importance of the light fitting being gas-tight.

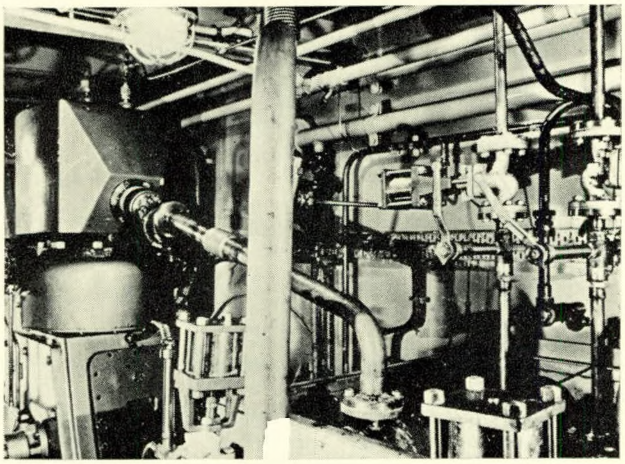


FIG. 16

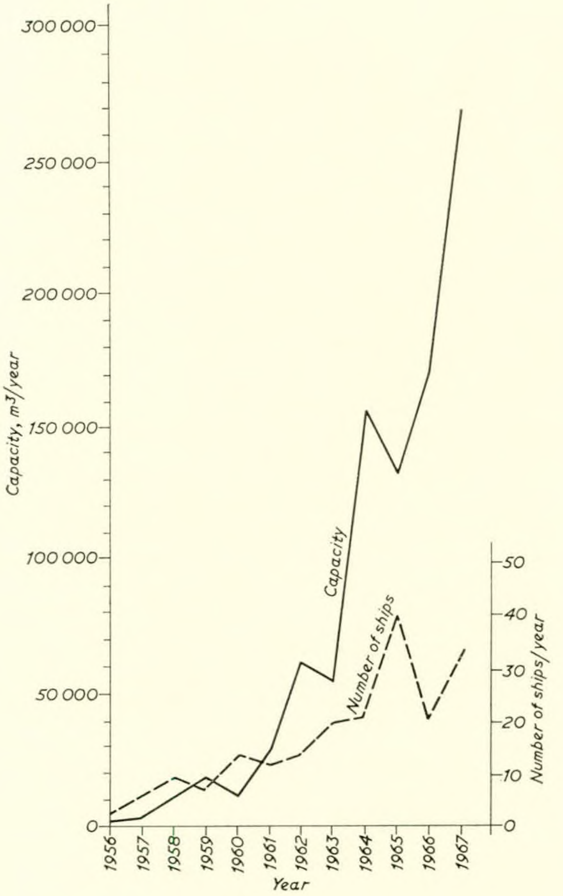


FIG. 17

Fig. 17 showed the development of liquefied gas carriers in the past ten to twelve years, between 1956 and 1967 the continuous line in the diagram showed the cubic capacity that had been introduced per year, and the figures for 1968 were way off the scale. The area under that represented nearly one and a half million to two million tons of shipping. The dotted lines on the slide showed the actual number of ships built per year, and those had been floating around the thirty to forty mark.

Fig. 18 showed the possible rate of development of liquefied gas carriers and the possible applications where the authors' compressors could be used. It was estimated that Western Europe's naphtha disposal for 1975 represented 750 million tons. However, they were really interested in the 39 million tons of petrochemicals since that represented one quarter to one third of the consumption in Western Europe, and the remaining two thirds or three quarters, in the region of about 120 million tons would have to be imported. Obviously, sea transport would have to solve that problem.

Hydrogen had an extensive explosive range i.e., between three per cent and 100 per cent. Although one might rely on the excellent dispersive property of the hydrogen into the atmosphere as a good enough safeguard, Mr. Navaz was sure that the authors would agree that it had been over optimistic to place all that reliance on that factor alone.

The capacity and power consumption curves, had been drawn on the basis of kilowatts against condensation temperature in °K (see Fig. 3). Mr. Navaz believed that what the authors meant by refrigeration capacity (Qe) was that it should be in kilowatt hours, in which case: 1 kWh=3412 Btu.

Fig. 8 showed a schematic arrangement for a reliquefaction system. The boil-off vapour was passed through the cylinder head heat exchanger by the difference in pressure between the cargo tank and the condensing pressure at the

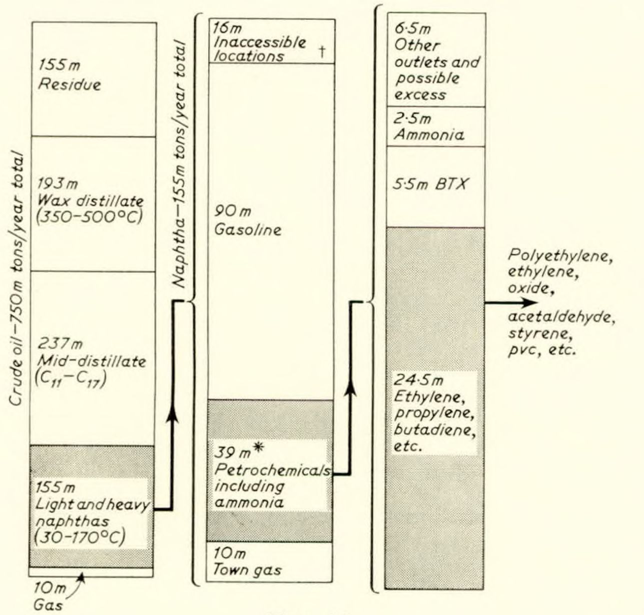


FIG. 18

cylinder head. That might be all right in the fully loaded or fully purged condition in the presence of small quantities of non-condensible gases, but during first charging operations, in the presence of large quantities of non-condensibles, such as inert gas, it might be difficult to deal adequately with rises in tank pressure without having to resort to excessive venting to the atmosphere at the cargo tank. That would lead to discharge of cargo vapour into the atmosphere which many shore authorities were not in favour of. Could the authors have been aware of that problem, which might be overcome by fitting a purge condenser?

The capacity to draw a slight vacuum in the cargo tanks was considered a useful facility which conventional reliquefaction plants were capable of, but which was beyond the capacity of the cold gas refrigerator.

In Fig. 10, the authors had proposed a separate Freon cooled air dryer before the air entered the fractionating column, thus freeing air from moisture. In a compact fractionating column for manufacturing liquid nitrogen for shipboard use, failure to adequately drain the extracted water from the air caused damage to the installation.

With NH_3 cargoes, the presence of CO_2 in the inert gas resulted in the formation of ammonium carbonate. Therefore, pure nitrogen vapour seemed to be the only suitable inert gas.

Again referring to Fig. 10, and in view of what constituted an inerted atmosphere in terms of allowable 0_2 per centage, with reference to a particular cargo, the provision of a mixing chamber prior to supplying either the containment space or the cargo tanks would help to provide further economy.

Since most liquid gas tankers were provided with inert gas generators for containment space flooding, as well as inerting and gas freeing purposes, and since the normal sea holding refrigeration load for the cargo was far less than that required for cooling down purposes prior to cargo loading, flexibility might be provided by inter-connecting the refrigerator on inert gas generation with the reliquefaction system or vice versa, as the condition demanded. All that would require additional safeguards and storing facilities.

Tables IV, V and VI showed the economic advantages resulting from the use of liquid air instead of liquid nitrogen, as a low temperature heat sink for refrigeration purposes on cargo containers.

It was noted that, with the use of liquid air, the authors were aware of the dangers of oxygen enrichment of evaporating liquefied air, but seemed to dismiss those as being mostly exaggerated and eventually preventable by technical means.

In spite of that, the use of liquid air had not been popular either in the United States, the United Kingdom, or Western Europe. Liquid nitrogen continued to be the popular refrigerant for container work.

In the U.S.A. alone 28 million cubic metres of nitrogen was annually used for refrigeration purposes. In view of the manner in which the containers were going to be handled by a number of unskilled personnel in different parts of the world, safeguards based on a process of anticipated failure and mishap should become the criterion for formulating safety requirements, rather than theoretically justifying a design system, and then waiting for the accumulation of accident statistics before safety requirements were legislated.

Most refrigerated containers carried refrigerated perishable cargoes, and oxygen starved atmospheres helped to retard the biological metabolism, thus helping to control growth and decay rates. Oxygen starved atmosphere had been approved for large refrigerated ships with simple audible, light and mechanical alarm devices to prevent loss of life. Such systems had been found to work satisfactorily for both staff and shore authorities.

As to shock freezing, there seemed to be a great future for its use on food processing ships.

Had the authors experienced any failures on the refrigerators, and what were the possibilities for commercial application of their refrigerator principle by the use of rotary compressors and expansion turbines, as proposed by Kapitsa?

MR. M. B. F. RANKEN (Member) said Mr. Meulenberg had shown one of the machines at the Refrigeration Congress in Ostend last year, and he was very impressed with its potential use for marine purposes.

They had been talking about the Phillips hot air engines for at least twenty years, and had been anxious to use the system in about 1947 for aircraft carriers. At the time it had not been properly developed, but now there was the practical machine which could do all the things required.

Mr. Ranken agreed that the idea of using methane was not worthwhile, since the horsepower involved was so enormous. However, it might have some applications for transferring, in terms of providing differences in pressure between different parts of the system for discharge or loading.

On the other hand, ethylene, was a very different proposition. He felt they ought to have some figures of relative costs in relation to the complete cargo handling system, because he felt they had to have something with which to compare, and there were no figures of costs at all in the paper itself. Perhaps the authors might rectify that in their reply.

Fractionating columns had always been a problem in ships. If high purity was needed columns were necessary but this applied mainly to naval purposes. For civilian applications high purity did not matter too much, and perhaps the column could be eliminated in most cases except where oxygen was to be produced for driers. Mr. Ranken was not entirely with Mr. Navaz who worried about oxygen enrichment, since he did not think that need occurred if one took proper precautions in the system.

Reduced oxygen was certainly a help for many chilled and frozen cargoes. On the other hand, for fruit cargoes, it might or might not be, depending on what one was doing with the fruit and whether one could control accurately. The system could work out simpler than a number of existing conventional systems that had been suggested for container ships. That was certainly to be hoped, but there were various difficulties, especially in dealing with the excessively low temperatures involved. Referring to Table V Mr. Ranken thought that a heat transfer coefficient equal to 0·2K $cal/m^2h°C$ was far too optimistic, and that the heat transfer coefficient would be two or three times as high in practice, as containers had to stand up to a great deal of rough handling.

On the other hand, if there were insulation and the container space were separately cooled, that would help to reduce the heat influx to the containers themselves.

On the matter of cryogenic freezing this machine was a break-through because there had been so much talk by salesmen about liquid nitrogen, with some suggesting fitting liquid nitrogen plant in ships, or tanks of LN_2 which had to be filled up with fish when they were empty and so on. As far as he was concerned all these ideas were just moonshine, but now the paper under review did show a machine which allowed them to do something on those lines, and it may have an application in factory ships in the future.

However, again, there was the problem of cost. The costs were in the region of something like four to six times the conventional method, e.g. five to eight times for liquid nitrogen. So there was still some way to go, although these actual freezing costs should not be exaggerated; they must be compared with the overall processing costs, of which they formed only a part.

Referring to the use of a smaller freezer, Mr. Ranken said that continuous operation was not an advantage of that method over others since it could be applied equally to an air blast or a contact method. The main point was that the smaller machine was portable and was very flexible for freezing the types of high value products involved. Mr. Ranken had heard that in the U.S.A. one company would shortly be using R12 for direct immersion freezing at sea of scallops. This method might well be a better proposition for these high value products than liquid nitrogen or even the machine being discussed here.

Mr. Ranken suggested that the authors ought to include a lot of figures for costs, etc. in their reply so that it would be possible to compare the machine with conventional methods for various systems.

MR. J. R. STOTT, B.Sc. (Member) referring to the use of liquid nitrogen for the carriage of refrigerated cargo containers, said that it seemed to him that the figures for power consumption worked out about seven times as high as compared with the consumption of a conventional system.

The authors had said nothing about costs, but if one looked at typical ships such as the new O.C.L. container ships, which had three working compressors, all about the same size as the Stirling compressors described in the paper, in place of those one would need eighteen of the Stirling compressors. The first cost would be four or five times as much as the conventional system.

Also, most carriers of refrigerated cargo carried frozen cargoes and fruit. To carry fruit by squirting in little drops of liquid nitrogen with the hope of getting away without freezing any fruit did not seem to be practical. That was all right for frozen cargo, but not for fruit.

If the authors' proposals were used on a large container ship there would be liquid nitrogen pipes running all round the ship. If one should burst there was danger of brittle fracture of the ship's structure. It seemed that they were offering a much more expensive plant which would carry half the types of cargo one would want to carry and introduce the hazard of brittle fracture to the ship. Mr. Stott wondered if the authors could give some idea of costs.

MR. G. C. COLLINS asked how the separation columns behaved in a seaway? How did they behave when they were not as stable as they would be on land?

MR. B. C. OLDHAM said that in Figs. 1 and 3 the term "condenser" was used which to a refrigeration man meant the disposal of the heat. Presumably, it indicated the condensing of the gas to be liquefied. Perhaps some other term such as "liquefier" should be used to make the point understood.

On the general design of the rhombic drive mechanism, Mr. Oldham asked whether there were any tangential crank efforts, torque or polar diagrams and the equivalent indicator diagrams which could be seen. The machine designers had no doubt prepared them when calculating stresses. However rough these might be, he would be glad to have a look at them.

MR. P. MELIA (Associate Member) said the CGR plant would appear to be capable of producing a perfect quality of inert gas. In practice it had been found that such quality was not required in normal tanker operation. It had also been proved that the inert flue gas installations fulfilled the requirements of safety and the inhibition of corrosion.

With regard to cost, it was doubtful whether the plant the authors had outlined could be installed at the relatively low cost of conventional systems. Compressing gas at the stated pressure, as against the normal practice, increased the operating costs in the ratio of 440 kW to 62 kW.

Safety features regarding pressurization:

a) of cargo tanks, with the normal working pressure of 2 lb/in^2 and a test pressure of 3·4 lb/in^2;
b) disposal of surplus oxygen;
c) storage of hydrogen supplies;
d) leakages;

would need serious consideration if the plant were installed in the engine room space.

The operation of the conventional inert gas systems had been kept as simple as possible, and could be started when required. When operating, the blowers were automatically matched to the varying requirement of the various tanker operating cycles.

What were the authors' views on how the corrosion of steel work was increased, provided that the normal SO_2 removal was obtained? The reverse had been found in service. Could the economics of the CGR system be justified in the face of published data with regard to conventional oil tankers? In practice, contamination of the products did not appear to have occurred, but had the authors some experience of this happening?

MR. B. A. PHILLIMORE (Member) pointed out that in the CGR machine on the hydrogen or helium side, reinforced Teflon rings had been used. It was fortunate that these were clean gases. Teflon rings had been considered for LPG applications, but there had always been reservations as to how long they would last.

Suggestions from quite reputable compressor manufacturers had been basically on the lines of opening up every so often and seeing how they were doing. Could the authors quote any figures for the Teflon rings?

Mr. Phillimore said that he thought he might have missed any direct comparison between cascade refrigeration systems for temperatures down to that for ethylene. One accepted the inherent simplicity of the Stirling cycle application for ethylene. At a quick calculation, at least so far as power was concerned, it would appear that the coefficients of performance of either the cascade system or the Stirling cycle engine were very similar.

Mr. Phillimore referred also to the comments on the use of the CGR machine for container ship duties.

He personally felt the question of oxygen concentration had probably been skated over a little and therefore the suitability of nitrogen as coolant might be regarded as "not proven". The emphasis in the paper had been on deep frozen produce. Of the refrigerated cargoes which were moved at the present time Mr. Phillimore suggested that a high proportion was still likely to be fruit cargo which might not be amenable, as Mr. Stott had already suggested. That might limit the application of the system for container ships.

The Tables showed that the authors had based their calculation on a 25°C ambient over 24 hours, which may or may not be questionable on a long voyage. For quite an appreciable part of the voyage one might have to cope with higher temperatures. The figure for the 20 ft × 8 ft × 8 ft container was also questionable.

With the best will in the world one worked on 40 Btu/h/°F ($18\frac{1}{2}$ kcal/h/°C) plus quite a lot of unknowns as against the figure of approximately 14 kcal/h/°C referred to in the paper. Mr. Phillimore worked out the heat leakage figure in the Tables at about 14°K for the containers even if the values of heat leakage were accepted, one would be a little worried about the call for power that was being proposed. Taking the ambient and the heat leakage figures given in the paper, and cross-referencing them and the liquid nitrogen production, in Tables IV, and V, Mr. Phillimore came to $8\frac{1}{2}$ kW power consumption continuously per container, give or take half a kilowatt.

In the modern concepts of container ships carrying a large number of containers, one hundred per insulated cell, and multiplying that up to three to six cells, the power consumption was very much less with a central refrigeration system. For one hundred, the figure would be at about $2\frac{1}{2}$ kW per container. For a fully refrigerated container vessel—highly refrigerated—500 to 600 kW would be a fair figure. The power consumption over the voyage, taking a higher ambient condition was only of the order of $1\frac{1}{2}$ kW per container. This tied up with the figure of six or seven times, which had been mentioned earlier by Mr. Stott.

In making that comparison one was accepting the present concept in which containers were mounted inside an insulated box. This gave a heat bridge between the ambient and the temperature inside the container which assisted in reducing the power consumption. Mr. Phillimore suggested that one could not necessarily make use of that with a liquid nitrogen system in that one would at least with low temperature cargoes be blasting out −20 or −22°C gas into the cell. There were some naval architects who might have objections to the quality of the steel which would be called for under those conditions.

One could not talk in terms of making a complete comparison between container systems because of the lack of cost figures. The numbers of refrigerated cells for the type of container ships at present under construction and envisaged as the future development, so far as British owners were concerned, would call for a very considerable number of CGR units, assuming that they were only made as a single size of machine.

He suggested that they should make a comparison with an installed cost of six hundred pounds per container for a large refrigerated ship, plus one-seventh of the power consumption for the CGR. It would be also interesting to hear from shipowners about the number of engineers available to top up the nitrogen bottles on 500 or 600 containers carried on a voyage of two and a half to three weeks. Also it would be worth having comments from ship builders on the capability of running cryogenic quality piping around the ship.

THE CHAIRMAN—Captain W. S. C. Jenks, O.B.E., R.N. (Chairman of Council)—said that he had had to work a fractionating column at sea, in Parliamentary language, to a party such as that present, one could not adequately describe how it worked. From the shipowning side of things he expressed interest in anything which dealt with the refrigeration of containers. Liquid nitrogen was used ashore for short term cooling of containers but from the seagoing point of view, the economics and the quantity which would be necessary seemed to preclude its use for long sea passages. It was a fact that although the arrangement in container ships for refrigerated containers was likely to be both effective and efficient, it had yet to be fully proved in service and there were certain disadvantages from the aspect of flexibility. It was unfortunate in an imperfect world that people adopted standards, and then immediately half the people in the world went away from those standards. If one designed for a certain standard container with air going in and out at certain places, and then the container height was increased by six inches it could no longer be used with a permanently installed ships' refrigeration system. Therefore one must always be interested in any possible alternative system, but he feared that the authors would have great difficulty in showing that their proposals were in any way economic.

Correspondence

MR. R. C. GRAY, in a written contribution, remarked that the cold gas refrigerator, manufactured at the Werkspoor Amsterdam works, was a magnificent piece of engineering in its compactness and quality of production. Unfortunately, the high production costs of the materials and design specification did not enable this equipment to compete effectively with alternative refrigeration systems in many applications. An increase in production might allow commensurate cost reductions and so make the cold gas refrigerator increasingly competitive.

Mr. Gray's company had made a thorough investigation of the alternative types of reliquefaction plant which were available for a liquefied gas vessel presently under construction. The vessel was to be suitable for the carriage of liquefied ethylene at −104°C, propane at −44°C or ammonia at −33°C, at about atmospheric pressure, and the company found in favour of the cascade type reliquefaction plant. In the operation of liquefied gas vessels there are several operating factors other than straight reliquefaction of the cargo, to be taken into account. Consideration must be given to operation of the plant with a content of incondensible gas, means to free the cargo tanks of gas for maintenance or for a change of cargo, removal of moisture from the cargo handling system etc., and for these other duties the vapour pump, or compressor, forming part of the conventional cascade reliquefaction plant, was very useful, a use which was not available with the CGR. Mr. Gray was of the opinion that the great advantage of the CGR was the compactness of the reliquefaction unit, and simplicity of normal operation in reliquefaction duty. The great disadvantages were the increase in first cost, and replacement cost of components damaged in service, the increase in electrical load and starting load for comparative refrigeration duties, and the inability to cater for the other factors briefly mentioned.

These comments were in no way derogatory, for the cold gas refrigerator was a wonderful example of precision engineering of a high standard, where modern materials and fabrication techniques enabled an ancient principle to be utilized and the equipment had many applications for which it was ideally suited.

MR. D. A. EATON (Member) wrote that cryogenics or the science of low temperature refrigeration had been used extensively ashore for many years, but was relatively new in the marine field. Oxygen and nitrogen had been liquefied so that they could be stored and transported in commercial quantities; the same applied to liquefied natural and petroleum gases. Small low temperature refrigerating plants had also been used at universities and other research establishments.

Mr. Eaton agreed with the authors that the prospects of the possible applications of low temperature refrigeration in the marine field would rise rapidly with the increase in the transportation of liquefied natural gases and liquefied petroleum gases, the use of liquid air or nitrogen for refrigerated containers and liquid nitrogen for inerting purposes in gas and chemical tankers.

The cold gas refrigeration machine was most ingenious, compact, efficient and capable of producing very low temperatures in one stage. None the less the plant such as shown in figures 10, 11, 12, 13 must be considered as a whole, since it was of little use having an efficient gas refrigerator should the equipment not function because of failures of ancillary or associated equipment. This was particularly the case in the marine field where far more problems existed and the experience was lacking because very few machines were operating under these conditions. This had been experienced after installing a very expensive plant for the purpose of producing and storing liquid nitrogen in a liquefied petroleum gas carrier for inerting purposes. Over the past two or three years the sole achievement had been to accumulate repair costs without adding noticeably to the supply of liquid nitrogen to the storage tank.

The vessel on which the equipment was installed was designed for the transportation of 11 453 m^3 liquefied petroleum gas under refrigeration at atmospheric pressure. The three cargo tanks were separated from the hull bulkheads and double bottom by a containment space or cofferdam and as it was intended that the vessel would carry a wide range of liquefied petroleum gases including butane, propane, butadiene and ammonia, with frequent switching from one cargo to another which necessitated the complete purging of tanks with inert gas, it was decided to install a nitrogen generating plant, complete with a fairly large storage tank. (The ideal inert gas is nitrogen because it is chemically inert and can be used to purge all gases without creating problems; it can be stored in liquid form in vacuum insulated tanks and, when converted into gas, it is dry, free from all moisture, an important factor in liquefied petroleum gas ships, as moisture forms solid hydrates which can be troublesome.)

The nitrogen installation consisted of a vacuum insulated tank with a capacity of 37 tons of liquid nitrogen and a CGR inert gas plant, similar to that shown in Fig. 10. The storage tank was athwartships in front of the bridge and above the level and aft of the deck house wherein the CGR equipment was situated. With this layout the liquid nitrogen from the fractionating tower, the piece of equipment shown as number 8 in Fig. 10, drained into a small tank from which it was pumped automatically through 55 ft of vacuum insulated delivery pipes plus a few feet of flexible anaconda hose to the main storage tank. The pump was controlled automatically by mercury float switches starting when the liquid rose to a predetermined level, stopping before the tank had been completely emptied.

Continuous trouble was experienced with the automatic switches in the small nitrogen storage tank in the CGR room and once, when the low level switch failed to stop the pump, the tank was drained and the pump seized up.

The capacity of the small storage tank was far too small for this particular installation, so that the quantity of liquid pumped at each operation only filled the long supply line to the main nitrogen storage tank and this vaporized in the pipe line while the small tank was filling prior to the next pumping sequence.

The result of these errors in design was that relatively warm gas and not liquid was entering the storage tank, and this tended to boil off part of the liquid already in the tank. It was never ascertained whether a negligible quantity of liquid nitrogen was added to the tank, or whether the loss was more with the plant running than would have been the case if the CGR plant had been stopped, when only the boil-off resulting from the normal heat leakage into the tank, took place.

The bottom cover of the fractionating tower was coned upwards, i.e. with the apex above the level of the base, and the drain was situated near the rim at the forward side. With the ship trimming stern it was impossible to drain the shell after defrosting and the remaining liquid froze causing the casing to fracture and the subsequent damage necessitated complete replacement of the fractionating tower, a large piece of equipment which had to be flown to the Persian Gulf for installation.

On another occasion, when the plant was in operation while the vessel was discharging cargo, ammonia gas present in the atmosphere was drawn in with the air and this solidified in the system thus rendering the plant inoperative.

The plant was designed to produce half a ton of nitrogen per day and the calculated loss resulting from the normal boil-off and the ship's consumption was estimated to be ¼ ton/day. The net result would have been an increase of ¼ ton/day. It was estimated that this would replenish the main storage tank after the purging of the cargo tanks for a change of cargo or for repairs inside the cargo tanks. It was soon found that the normal boil-off appeared to be increasing and it was decided to fit a vacuum gauge to ascertain the vacuum in the annular space around the nitrogen storage tank. The gauge indicated that there had been a fall-off in the vacuum and this materially affected the heat losses into the cold interior chamber containing the low temperature liquid nitrogen. An Edwards rotary vacuum pump was installed and permanently connected to the vacuum space of the tank; this was run periodically to maintain the vacuum at, or below 0·01 TORR with resulting improvement in the loss of nitrogen. The Edwards vacuum pump proved to be a simple and efficient machine which could produce a very high vacuum. It was not so easy to ascertain the amount of vacuum in vacuum-insulated nitrogen supply lines and so far nothing has been done with this equipment.

Another problem was that the electric supply to the CGR machine and its associated pumps came off the deck supply line and whenever there was an emergency shut-down on deck the nitrogen plant stopped. Unless the plant was restarted very quickly, there was a considerable delay in drying the air to get the plant back into operation.

Low pressure refrigeration was possible on board ship but care had to be taken in the layout and much more consideration should be given to details because the equipment had to work on seating which was continually moving and in a humid salt laden atmosphere, also vibration on board ship was much more pronounced than it was ashore.

The CGR compressor was protected by various pressure and temperature cut-out devices. Absence of instrumentation and experience presented difficulties in determining when irregularities in operating cycle have arisen.

Experience had shown that cut-outs sometimes occurred for no apparent reason leaving the staff to ponder on the cause. Comprehensive training in CPR operation would appear to be necessary for continuous and trouble free operation.

The present standard of CGR equipment appeared to be more suitable for laboratory or shore conditions, but the correct orientation of the compressor and its ancillary equipment could change the position.

A modification of the design of the bottom of the fractionating tower so that it could be dished outwards with a drain on centre line, would avoid the problem encountered with the equipment.

If the plant were situated above the level of the main storage tank the liquid could be run down by gravity; the length of the delivery pipe should be kept to a minimum.

If pumping equipment were necessary, mercury float switches were totally unsuitable for marine application.

Equipment and instrumentation should be mounted on anti-vibration devices and spares and services should be available world-wide.

Even helium for charging compressors was often difficult to obtain on a world-wide basis.

Authors' Reply

Replying to the discussion, the authors thanked those who had taken part, both at the meeting and in writing. Their contributions were representative of current thinking in the shipping industry about the use of very low temperatures such as −200°C (−328°F).

Mr. Navaz had asked for comparative costs of the CGR-units and conventional refrigeration units making use of the change of state process and the Joule Thompson effect.

In Fig. 19 the investment per unit of refrigeration (Dfl/kW) for some refrigeration systems was shown as a function of the total installed refrigeration capacity of the plant and of the refrigeration temperature to be generated.

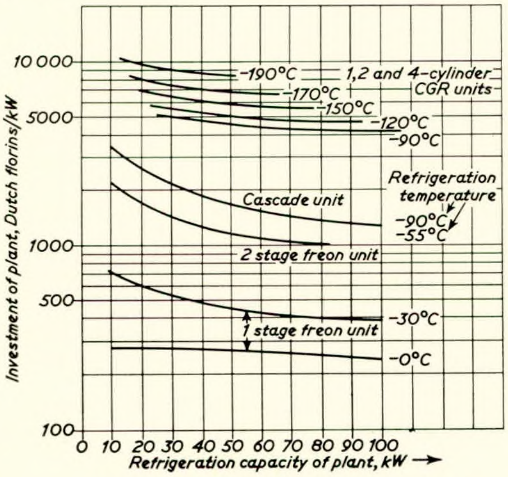


FIG. 19

The conventional freon and cascade plants were assumed to generate their refrigeration capacity in a heat exchanger, absorbing heat at low temperatures, just as the CGR-units did in their condensers.

The cascade unit comprised a closed ethylene loop and a two-stage freon loop. The costs were based on equipment as supplied ex works, without erection costs at site.

Because the CGR machinery could be considered as packaged units lower erection costs could be expected than with conventional machinery.

From Fig. 19, it was obvious that when only investment costs were considered for the higher capacity and temperature ranges the CGR machinery could not compete with conventional cascade plants when designed as one unit for the capacity concerned. Fig. 20 gave an idea of the efficiency data for these systems.

Mr. Navaz questioned the method used to leak test the CGR refrigerant lines when hydrogen was used as the cycle medium.

The procedure for leak testing the closed cycle and hydrogen lines was:

i) a first check on tightness of the hydrogen system was carried out by a pressure test, whether or not there was a pressure drop when the closed system filled with gas was checked over a certain period.

ii) a second check for rather larger leakages was soap testing of all joints, gas leakages eventually becoming visible as gas soap bubbles.

iii) a check for smaller leakages was to measure the explosiveness of the atmosphere around the hydrogen-containing components and joints, the ambient atmosphere being checked with a mine gas detector for the existence of explosive gases, a percentage as low as 0·3 per cent of explosive gas in the air could be measured with the particular detector used.

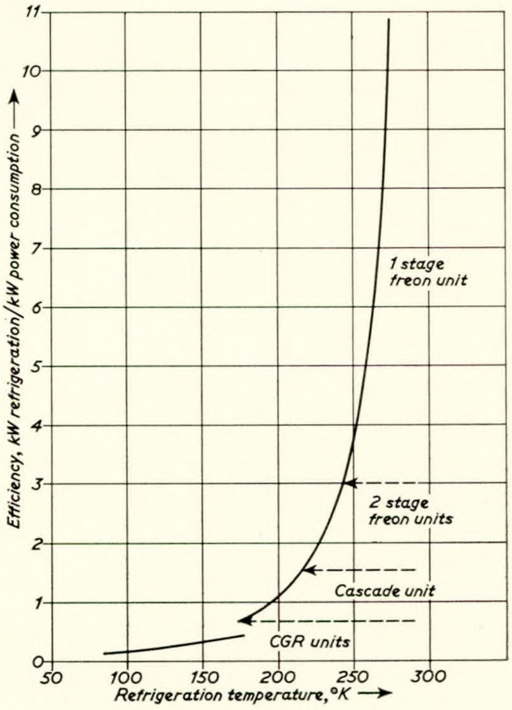


FIG. 20

Mr. Navaz's belief that the authors had meant to state the refrigeration capacity Q_E in kWh instead of kW, had to be contradicted. The refrigeration capacity Q_E was the quantity of refrigeration units in Btu produced by the CGR in a certain time period in hours, i.e. it had to be expressed in Btu per hour or kW ($3412 \frac{\text{Btu}}{\text{h}} = 1$ kW).

The problem of the existence of non-condensibles in the gas to be liquefied had been recognized and dealt with. The non-condensibles would be sucked in by the CGR condenser together with the gas to be liquefied, but they would be collected in the top of the condenser and not discharged from it with the condensate. The increase in the percentage of non-condensibles would provide a drop in the condensation temperature, which would be adjusted automatically to the increasing concentration. When a sufficient quantity of non-condensibles was collected, they were blown off to the free atmosphere via the vent system. Because the non-condensible concentration could be increased, the quantity of cargo vapour to be blown off with the non-condensibles could be considerably limited.

The use of a separate purge condenser and compressor, as used with conventional cascade liquefaction plants and as proposed by Mr. Navaz could also be considered, as such a set-up also provided an increase in the concentration of non-condensible gases in the gas mixture to be blown off, just as in the CGR condenser.

It was true that the CGR could only draw a slight vacuum in the cargo tanks with dropping condenser temperature. In the ethylene carriers *Teviot* and *Traquair,* mentioned in the paper, not even such a slight vacuum was permitted. This was to prevent eventual explosions of the square modelled cargo tanks. The possible drawing of ambient air into the ethylene system under vacuum conditions was not favoured. However, for other CGR applications certain gas pump facilities for gas freezing and purging of the cargo tanks had been provided.

By the expression "mostly exaggerated" in connexion with the dangers of oxygen enrichment of liquid air, the authors had meant that these objections to the use of liquid air were mostly vague and inaccurately defined. Such arguments, which appealed to a general fear among non-experts of explosions, were often used by prejudiced parties who were only able to produce or supply liquid nitrogen.

TABLE VII

COMBUSTIBILITY OF GASES

Gas	Explosion limits, percentage gas		Combustion speed, m/sec		Ignition temperature	
	in air	in O_2	in air	in O_2	in air	in O_2
H_2	4·1...75	4·5...95	2·67	8·90	510	450
CO	12·5...75	13...96	0·33	1·10	610	590
CH_4	5...15	5...60	0·35	3·30	645	645

Table VII gave some data concerning the combustibility of the highly explosive gases, hydrogen, carbon monoxide and methane, mixed with an air or 100 per cent oxygen atmosphere. From Table VII it could be seen that the lower explosion limits and the ignition temperature were little influenced by higher oxygen concentrations. The combustion speed, however, was increased by a factor varying from 3 to 10. But combustion had still to be started by ignition temperatures of the same level, while the high combustion speeds were only valid for a 100 per cent pure oxygen atmosphere. Because of heat leak through the vacuum insulation, such a 100 per cent oxygen atmosphere could hardly be arranged by oxygen enrichment of liquid air in a storage tank.

The enrichment of liquid air with 21 per cent oxygen as a function of the time and the evaporation loss as a percentage of gross tank volume per 24 hours, was shown in Fig. 21. A normal heat leak into the small liquid gas bottles used for container refrigeration was in the region of 2 per cent of the tank gross content per day. When the bottles were completely filled with liquid air and not used for five days the oxygen concentration of the liquid grew to 22·5 per cent. But when, in the meantime, liquid air is discharged for refrigeration purposes the enrichment will be even less.

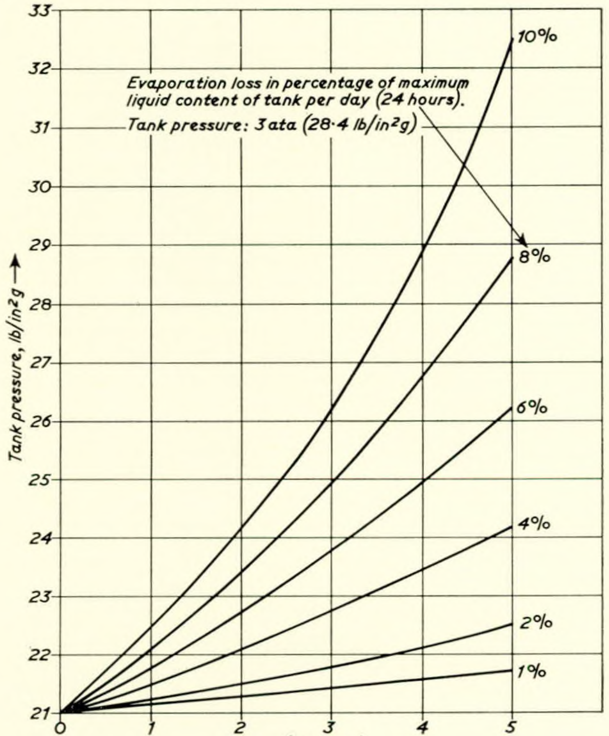


FIG. 21

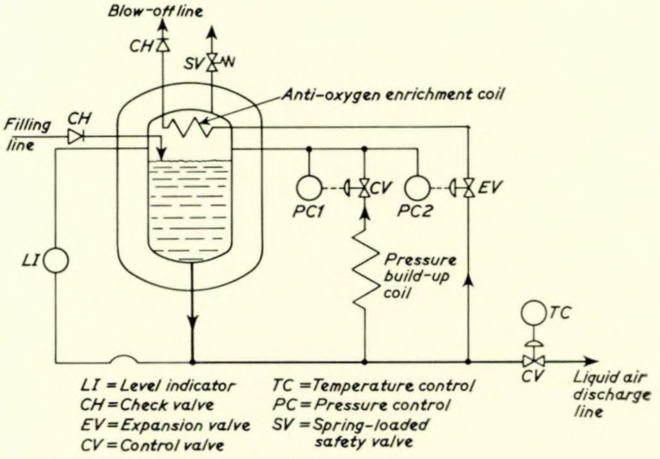


FIG. 22

Fig. 22 showed an anti-enrichment coil, with which a liquid gas tank could be equipped to prevent oxygen enrichment. Because nitrogen had a lower boiling temperature than oxygen, the nitrogen concentration of the vapour above the liquid air in the tank would be higher than the nitrogen concentration of the liquid air itself. This resulted automatically in a growing oxygen concentration of the remaining and decreasing quantity of liquid air, when vapour from above the liquid was blown off. Therefore direct blowing off of vapour from the space above the liquid must be prevented.

When the pressure in the tank shown in Fig. 22 had grown as a result of the heat leak through the vacuum insulation, the pressure control (PC 2) opened the expansion valve (EV). Some liquid air was expanded in this valve (EV), resulting in a pressure and temperature drop of this liquid air. The evaporation of the same low pressure liquid air inside the coil, mounted in the vapour space of the tank, provided a condensation on the outer coil surface of high pressure vapour, by which the tank pressure would again drop below its adjusted value. The evaporated low pressure liquid air was then blown-off to the free atmosphere. In the authors' opinion the fact that liquid nitrogen was more popular than liquid air could not be considered as evidence that liquid air was much more dangerous than liquid nitrogen. The greater popularity of nitrogen resulted from the historical development of the industrial gas industry. All gas producers operated basic oxygen producing air splitting plants, which were generally incapable of producing liquid air. The market price of oxygen was higher than that of nitrogen. So the gas producers extracted the oxygen from the air in the first place and then sold the nitrogen for a lower waste product price.

In so far as Mr. Navaz dealt with the subject of anticipated failure and mishap when the liquid air refrigerated containers were handled by unskilled personnel, the authors would just mention that liquid gas users already had to deal with the dangers of nitrogen. The fact that a container could not be entered by human beings before the suffocating atmosphere was replaced by an air atmosphere was obviously not liked, but it was accepted.

A reason for using nitrogen as container refrigerant was that an oxygen starved atmosphere helped to retard the biological metabolism of perishable cargoes, refrigerated at higher temperatures than deep frozen goods. On the other hand most blood-rich deep frozen products showed discoloration when stored in an oxygen starved atmosphere, while a progressive growth of detrimental bacteria propagating in an oxygen-poor atmosphere, could occur during a longer stay in nitrogen.

It seemed that the most suitable refrigeration gas would be a nitrogen-oxygen mixture with an oxygen concentration somewhere between that of air and of pure nitrogen. Therefore the authors felt that for container refrigeration liquid nitrogen had to be preferred to liquid air as a refrigerant.

Answering Mr. Navaz's question concerning CGR failures during field operation, the authors were of the opinion that the CGR units had proved themselves quite satisfactory. Some problems had been met in connexion with dissolved and solid pollutions of cooling water, resulting in precipitations on the cooling surface of the CGR coolers. The lubricating oil seals of the stuffing boxes had also proved to be sensitive, in particular higher operating temperatures, due to a high cooling water temperature and the use of helium as cycle medium, were found to affect their operational performance.

As described in the paper, the refrigeration capacity of the CGR, based on the Stirling cycle, originated in compression at high, and in expansion at low temperature of the cycle gas. This compression and expansion were achieved by means of reciprocating machinery. Compression and expansion could, however, also be arranged in rotary compressors and expansion turbines. These refrigeration systems, which could be considered as a reversed gas turbine cycle, were known as the Claude cycle and had been introduced by Kapitsa. The Stirling, and the Claude cycle could be designed for refrigeration temperature levels between −100°C (−148°F) and −200°C (−328°F). The Stirling process was more efficient than the Claude process for the higher temperature range, i.e. between −100°C and −160°C (−256°F), while for lower temperatures the Claud process was more efficient.

It was evident that the natural application area of the Stirling system, based on reciprocating machinery, was in the smaller capacity ranges. For higher capacities the rotary machinery would come into the picture. However the rotary machinery was limited in that it could only be built for a certain minimum throughput. Technically and economically a Claude cycle could be constructed for a capacity of about four cylinder heads of the CGR machine and for a refrigeration temperature of around −200°C (−328°F).

Mr. Ranken's wish that a photograph of a CGR unit be published was fulfilled in Fig. 23 which showed a 1-cylinder machine. In answer to his question on the relative costs of refrigeration machinery and its power consumption and in particular those of the CGR machinery, the authors would refer him to Figs. 19 and 20.

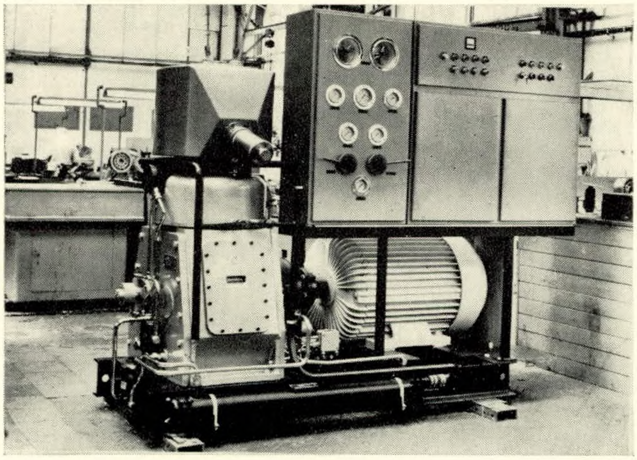


FIG. 23

The authors agreed with Mr. Ranken on the subject of oxygen-enrichment of liquid air and would refer to their earlier comments on the subject.

In Tables V and VI a heat transfer coefficient of 0·20 (kcal per m^2h°C) for a 20 ft container was mentioned, and Mr. Ranken had commented that this was too optimistic a figure. The source of this figure was an official test report on newly built containers produced according to the sandwich principle. The skin plates were of reinforced polyester and the core of polyurethane foam. These sandwich elements were glued together with a polyester resin. The containers had not yet been in operation long enough to get an impression of the eventual increase of the heat transfer coefficient after longer operation periods and rough handling of the containers.

Mr. Ranken referred to data for freezing costs as mentioned in a paper* read at the Congress on Refrigeration in September 1968 at Ostende, Belgium. In this paper the freezing costs of conventional freezing systems, i.e. airblast and fluidized bed freezing, at refrigeration temperatures of about −40°C, were compared with cryogenic freezing; i.e. cryogenic freezing with nitrogen supply from a gas producer to the freezing site as well as cryogenic freezing with liquid air production from CGR-units at the freezing site itself.

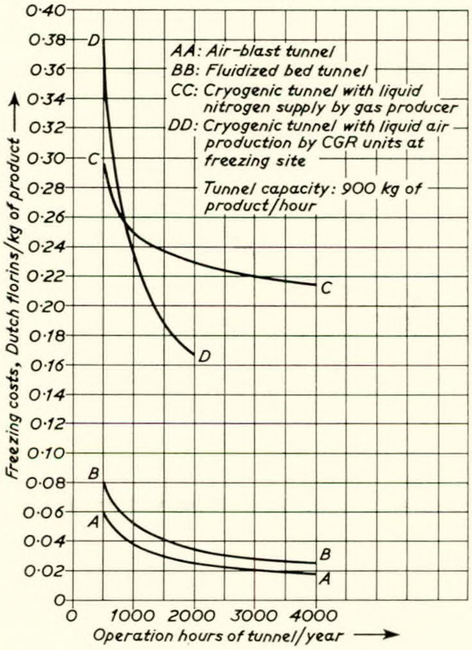


FIG. 24

Fig. 24 gave a résumé of the freezing costs of the various systems as a function of the tunnel operation hours per year for a tunnel capacity of 900 kg (2000 lb) product per hour. The curves were based on the following assumptions:

1) a nett refrigeration requirement of 80 kcal/kg product (145 Btu/lb);
2) a capital investment service for depreciation and interest of 17 per cent of the investment per year;
3) a price for electric power supply of 0·07 Dfl/kWh;
4) a price for liquid nitrogen as supplied by the gas producer to the freezing site of 0·18 Dfl/kg LIN;
5) a cooling water price of 0·06 Dfl/m^3;
6) a charge of 5 per cent of the investment per year for maintenance;
7) no charge for manpower for operation of plant and handling of product.

---

* "Cryogenic Quick-freezing tunnel with refrigeration by Cold Gas Refrigeration (CGR)".

From the comparison of pure freezing costs it could be concluded that cryogenic freezing with liquid nitrogen, supplied to the site, was more expensive by a factor of 6 to 8 than the most advanced conventional freezing system, the fluid bed tunnel system and that cryogenic freezing with a small liquid air plant on freezing site, gave a comparable and competitive cost level with respect to cryogenic freezing with liquid nitrogen, supplied to the site by the gas producer and produced in a large tonnage plant.

On that fact pure freezing costs of cryogenic freezing were about 5 to 8 times or at least 4 times more expensive than conventional freezing, Mr. Ranken commented that there was still some way to go. Although with the growing popularity of the use of cryogenic techniques this price difference would probably decrease slightly, it could never be expected that the price of the cryogenic freezing would drop to the level of conventional freezing. This was also obvious from Figs. 19 and 20, when one considered that conventional freezing systems generated their low temperatures at the −40°C temperature level and cryogenic freezing systems at the −180°C level. Therefore there would have to be good arguments to justify the higher costs of cryogenic quick-freezing of certain products. Some of these arguments were based on improvement of quality from a decrease of cellular breakdown, less desiccation, less separation of fat and a decrease in protein denaturation. Cryogenic freezing would preferably be applied for the more valuable products with a low resistance against freezing effects.

Mr. Ranken referred to a new freezing system to be developed, based on direct immersion of food products in freon 12. Considered from the thermodynamic point of view and in accordance with Figs. 19 and 20, freezing in a boiling liquid freon of around −30°C would be cheaper than cryogenic freezing at −180°C. However, from a practical point of view there were still some technical problems, which did influence the economy of this immersion freezing. To supply and discharge the food products to and from the immersion bath or spraying zone, the freezing chamber needed a periodic or continuous open connexion with the ambient. Here some leakage of air into the freon system would take place, and freon vapour would also be lost to the atmosphere—this in particular would have to be greatly limited to make the system economically feasible.

Mr. Scott's conclusion that LIN refrigeration of containers on board was roughly four to seven times more expensive than conventional refrigeration by means of a central "freon-cold air" system on board was correct and roughly according to the data mentioned before in the comparison of conventional and cryogenic freezing equipment. But the pure refrigeration costs on board alone might not be the only and most important argument for the choice of the refrigeration system. Shipping people and owners had to prepare themselves for container transport from door to door. This meant that the economy and reliability of the container-refrigeration on shore also had to be considered. For the individual and unattended on-shore transport of refrigerated containers, the liquid nitrogen system had proven itself economically feasible and reliable, especially where non-expert staff was involved.

On the size of the installation and the eighteen CGR units needed for the container ship the speaker had in mind, it could be remarked that for such a capacity the plant would have to be based on rotary machinery and not on CGR units.

According to Mr. Scott, direct contact of nitrogen spray drops and the refrigerated perishables would ruin the food products. The authors' opinion was that these drops must be evaporated before entering the cargo space. This could be achieved by spraying the LIN in a space between container roof and an aluminium shroud mounted above the cargo. The LIN spray first evaporated on this shroud before entering the cargo space underneath the shroud.

The comment that on a large container ship LIN pipelines would run all around the ship could not be denied, but to say that a burst LIN pipe must lead to brittle fractures of the ship structure was too pessimistic. In the first place a good moisture proof insulation around the LIN piping was required. Should a LIN pipe crack, the first leaking LIN drops would be evaporated within the insulation. The generated vapours would be blown off from the valves mounted on the outer moisture proof piping around the insulation.

In the second place, safety devices for protection against total LIN pipe bursting would have to be arranged. Such devices could be pressure control equipment along the LIN pipe network, that swiched off the LIN supply pump in case somewhere the LIN pressure fell off due to pipe bursting.

Lt. Cdr. G. Collins' question on the stability of the rectification process in a seagoing separation column originated from the knowledge that on-shore separation columns had to be carefully erected in a vertical position.

A column comprises of a vertical cylinder with horizontal trays. These trays were either simply perforated or equipped with more advanced bubble caps. With an operating column liquid was found on the trays, while, through the plate perforation or through the caps, a gas flow rose through the liquid layer to the top of the column.

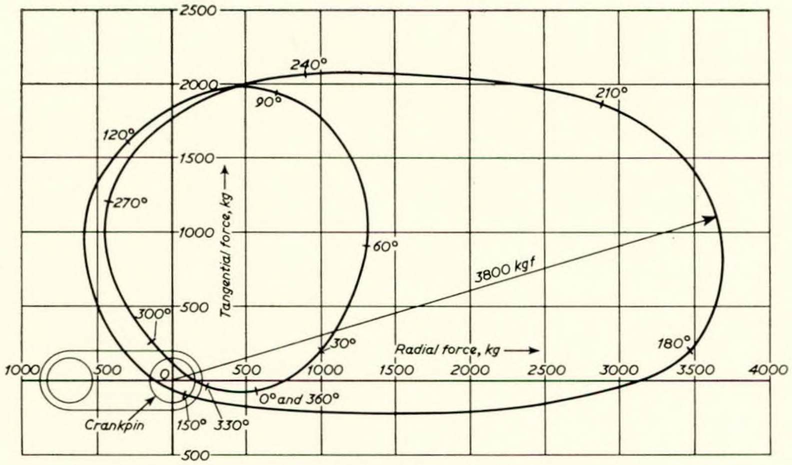
It was quite obvious that with a permanent deviation of the column from the vertical position, i.e. a permanent deviation of the trays from their horizontal position, the liquid would flow to one side of the trays. In the most severe case the rising gas flow would pass through the perforation fallen dry, the rectification process thereby ceasing to operate so that the purity of the column products could be guaranteed.

On a seagoing column, liquid movement on the trays and a permanent accumulation of liquid at one side had to be prevented. Fortunately such a seagoing column did not have a permanent deviation from the vertical, but as a result of the moving ship, a varying deviation, with only slight liquid movement to and fro on the trays and not a permanent accumulation of liquid at one side. To further equip the columns for operation at sea, the trays were to be equipped with liquid flow barriers to prevent a too spontaneous transport on the trays. Furthermore the column had to be provided with equipment by which an average vertical position could be arranged.

Mr. Oldham understood the expression "condenser" very well. It was indeed related to the medium to be liquefied in the CGR, i.e. in this condenser condensation of the CGR's cycle gas did not take place. As mentioned in the paper the cycle gas remained in the gaseous stage throughtout the complete process.

Fig. 25 was a tangential—or short diagram of the CGR rhombic drive. This polar diagram of the load on crank pin of one of the two crankshafts had been used for design of crank pin bearings, but did not indicate the non-existence of free inertia forces, i.e. about the total balancing of the rhombic drive per cylinder unit of the CGR. This total balance could be better understood when one considered that for each moving mass, i.e. working piston assembly, displacer assembly, connexion rods, crank and counterweight, a similar mass with an opposite direction of movement existed. It was important to understand that the mass of the working piston assembly the piston, piston rod, piston rod yoke and a part of its pertaining connexion rods, equalled the mass of the displacer assembly, i.e. the mass of displacer, displacer rod, displacer rod yoke and its pertaining connexion rods.

Mr. Melia stated that conventional inert gas systems, based on flue gas installations, sufficiently fulfilled the requirements of explosion safety and inhibition of corrosion of ship steelwork. The authors agreed to this so far as it concerned cargoes such as crude oil, fuels and many of the chemicals shipped in bulk today, but they were of the opinion that in future the shipping world would also have to deal with cargoes for which an inert gas without any carbon



Average H_2 pressure: 35 kg/cm²
Average cooling water temperature: 15°C
Condenser temperature: 75°K
Rotation speed: 1500 rev/min

FIG. 25

dioxide content and with a narrow limited purity would be required. This opinion was based on the fact that already many chemical production plants on shore got their inert gas supply from high purity nitrogen units based on air separation. This was because the cheaper conventional flue gas systems could not meet the composition and purity of the inert gas as required by the process in these plants. The authors wanted to call attention to these high purity nitrogen units for possible use in future. Some small liquid nitrogen plants for on-board production of rather impure nitrogen (99·5 per cent N_2) were known to be installed, but were not in operation for a long time. The authors did not have sufficient experience to answer the question on the influence on the corrosion of ship steelwork of the proposed use of high purity nitrogen as an inert gas.

With respect to the question on the economics, it was obvious that a CGR system could never be justified for use on crude oil, fuels, and basic chemicals, where the cheaper flue-inert gas, containing N_2, CO_2 and some SO_2 and H_2O, still met the products requirements.

Mr. Phillimore was interested in figures on the operation of ceramic reinforced teflon rings and referred to the advantageous clean operation condition with which these rings had to cope in the CGR.

Testbed experience was that in the CGR the wear of these rings could be tolerated at an operation time of 8000 hours. The operation conditions for the three rings of the working piston were:

i) a varying pressure difference over the piston between +13 and −13 kg/cm² (+185 lb/in² and −185 lb/in²);
ii) an average piston speed of 3·75 m/s;
iii) hydrogen as cycle medium;
iv) operating temperature around 100°C.

The authors' experience was that the lifetime of the rings was greatly influenced by the quality of surface finishing of cylinder liners and in particular by the operating temperature of the rings. With higher operation temperatures the operating lifetime would decrease exponentially.

Mr. Phillimore calculated that the power consumption for the production of the liquid nitrogen used for container refrigeration was a factor six to seven times higher than the power consumption for container refrigeration by means of a conventional central "freon-cold-air" system. This figure, based on LIN production with a CGR unit, corresponded with data mentioned before and the authors would refer to replies already given. But they wished again to accentuate that power consumption or investment of the plant on board might not be the only arguments on which the possible preference of the conventional refrigeration system would be based. On-shore unattended refrigeration during transport must also be considered.

It could be noticed that power consumption would be reduced by about 30 per cent when the LIN was produced in a plant based on rotary machinery and of a capacity of 10 to 20 times that of a one-cylinder CGR air separation plant.

For his comparison of power consumptions, Mr. Phillimore had used the present concept of the container ship in which the conventional refrigerated containers were mounted inside an insulated cell. He mentioned the advantage of the additional heat barrier between the ambient and the temperature inside the containers, resulting in a reduction of power consumption for the conventional system and suggested that such an insulated cell could probably not be applied for LIN refrigeration, because the waste nitrogen at −20°C would be blasted into this insulated cell space. The naval architects might have objections to this low cell temperature, because of the quality of steel to be applied for the steel structures, construction and supporting elements present in the cells.

The authors noticed that the advantage of the additional heat barrier ambient and the inner temperature of containers was also valid for LIN refrigerated containers stowed in an insulated cell. With respect to the quality of steel for the structure elements in the cell a fine-grained non-alloyed carbon steel (grade E steel) was advised for this −20°C normal service temperature.

The question was whether this cell temperature of −20°C would ever be obtained by the waste nitrogen blown-off from the containers in the cell.

On the point that for on-board LIN refrigeration of the containers, presently under construction and envisaged for the future, a very considerable number of CGR–units would be called for, the authors referred to their earlier comment that rotary machinery had to be considered for capacities above four cylinder heads of the CGR.

To limit the number of engineers necessary to refill the LIN bottles of five to six hundred containers during two to three week voyages extended automation of this duty was required. It must be feasible to apply a pneumatic system with which the ship LIN line branches were plugged in to the container bottle filling lines as soon as the containers were hoisted and stowed on board. The intention was simultaneously to refill all present container bottle sets by pressurized LIN supply via these main and branch lines. The authors had already commented on the subject of the LIN pipelines.

At the meeting Mr. Meulenberg had mentioned some data concerning running periods for CGR units on board ship. More detailed information could now be given. The ethylene carriers *Teviot* and *Traquair* were both equipped with two 1-cylinder CGR units, one in operation and one a stand-by machine. The carrier *Thales* had three units of which, for extreme conditions, two units were to be in operation and one in stand-by service. The hour counters of the units of the three vessels had indicated, in March 1969, around 11 000, 8000 and 2000 hours for respectively the *Teviot, Traquair* and *Thales* CGR machines.

Mr. Gray's contribution to the paper was in some respects self-explanatory. The investigation of alternative types of reliquefaction plants referred to had been carried out as a technical and economical comparison and evaluation of two refrigeration systems on request of the owner. The first system was a conventional cascade reliquefaction plant as engineered and to be built by the Mr. Gray's company and the other system was based on CGR units as offered by the authors' company.

So far as the authors understood it, this cascade system comprised a primary and secondary refrigeration loop. In the primary loop the cargo gas to be condensed was applied as refrigerant and was probably compressed in oil free compressors and condensed at high pressure in an evaporator-condenser, after which the H.P. condensate was expanded and returned to the cargo tank via a Joule-Thompson expansion valve. In the secondary loop freon was used as refrigerant, which was evaporated in the evaporator-condenser at low pressure, was compressed in compressors and reliquefied in a water-cooled condenser and then returned at low pressure again to the evaporator-condenser via a J. T. valve.

Although such a cascade system must be rather complicated, it had the advantage of having cargo gas compressors available, an advantage which the basic CGR lacked. These cargo gas compressors could be used for such duties as gas freezing, etc.

To meet these cargo gas pump requirements CGR reliquefaction systems for other ship owners had been equipped with additional simple gas blowers.

Because the offer for the cascade system came from another party the authors had not been able to evaluate precisely the so called disadvantages of higher CGR plant costs compared with cascade plant costs for this particular ship. However, the fact that CGR plants for ship reliquefaction plants had been repeatedly ordered by other yards and owners seemed to prove that the cost differences were marginal and open for evaluation and discussion.

The authors expressed their thanks for the opportunity of discussing the CGR system with the writer during the project stage of the carrier concerned. That discussion had extended the experience of all involved.

Mr. Eaton had written an extended but also pessimistic account of his experience of the operation of a CGR liquid nitrogen plant or board an L.P.G. and ammonia carrier. He considered nitrogen as an ideal chemically inert gas, with the advantage of possible storage in liquid form and providing a dry and moisture-free purge gas when evaporated; this being important because moisture could form troublesome solid hydrates with L.P.G. cargoes.

He concluded that the CGR equipment for LIN production as described by him was still too much a laboratory plant in its development stage and not adequate for rough shipboard operation.

The authors agreed to this latter statement so far as it concerned the CGR plant described by Mr. Eaton. This plant was not made by the authors' company but its system was well known to them, so that some important differences with the LIN plant proposed for ship use as shown in Fig. 13 could be mentioned:

The LIN plant in Fig. 13 did not need a periodically operating LIN pump, controlled automatically by mercury float switches, but constantly supplied its LIN product flow from vessel (11), with an overpressure of about 2·5 kg/cm^2 (35 lb/in^{2}g) to storage vessel (13) at atmospheric pressure. The troubles arising from mercury float switches on a moving vessel, of the periodically operating LIN pump and consequently the heating-up and cooling-down of the long LIN line after the pump, were thus avoided.

The LIN plant described by Mr. Eaton dried and purified the intake air by means of snow precipitation in a heat exchanger, i.e. water and carbon dioxide were separated from the air by freezing out. Because this heat exchanger, the so-called snow separator, would have to be defrosted periodically, the whole plant had to be shut down. These defrostings required, before every start-up, a troublesome total drainage of water and careful drying of the plant. This was a particular nuisance when the position of the drain valves were not adapted for application on a moving vessel.

With the plant in Fig. 13 the largest part of the intake air was already dried by a constant drain of water in liquid form from the pressurized air in the coolers (2) and (3). The rest of the moisture and the carbon dioxide were absorbed in one of the three regenerative absorbers (4), (5) and (6), of which one was in operation, one in the heating-up or regeneration stage, and the third in the cooling-down stage. This system had the advantage, that traces of other gases like L.P.G. and ammonia would also be caught in the sieves before being solidified by the low temperatures prevailing in the system and providing stoppages.

Short interruptions of the electrical supply to the plant would not be too big a nuisance, because the unit could be started-up again directly without any drying. Mr. Eaton remarked further that with the LIN plant described by him the impression existed that not even a positive production surplus could be obtained, due to insulation losses of vacuum insulated lines between pump and storage tank. The expected production surplus was probably calculated by deduction of the insulation losses of vacuum lines and storage tank and of the ship's consumption from the LIN production capacity. The figure used for the insulation losses of the storage tank had probably been the figure for normal boil-off losses of the static tank, completely filled with LIN. The authors' experience, however, was that the boil-off losses of storage tanks during filling were much bigger as a result of insulation losses in filling lines and valves belonging to the tank. This increase in the normal boil-off by the filling procedure was generally of no importance, because the filling time was negligible with respect to the time for static storage. But with the small LIN production units and consequently constant filling this additional boil-off loss had to be reckoned with. That these additional losses would cover the expected net LIN production result or could even be superior to it they could well imagine.

The authors were of the opinion that LIN production on board was quite feasible, but the system design had to be provided by experts in cryogenic techniques in close co-operation with naval technicians, because the proposed equipment could still not be considered as common practice and part of the know-how of naval architects and shipbuilding engineers.

CORRIGENDUM

In the contribution by Mr. K. Brownlie (Associate Member) to the discussion on the paper "Steam Turbine Machinery" in the May issue of TRANSACTIONS, p. 154, lines 12–14 should read ". . . since for a given number of stages the diameter was proportional to the reciprocal of the speed. . . "

ANNUAL DINNER

The Sixty-sixth Annual Dinner of the Institute was held on Friday, 14th March 1969, at Grosvenor House, Park Lane, London, W.1., and was attended by 1380 members and guests.

The President, F. B. Bolton, Esq., M.C., was in the Chair. He was supported by the Chairman of Council, Captain W. S. C. Jenks, O.B.E., R.N.

The official guests included: His Excellency Mr. Erling Kristiansen, The Danish Ambassador; His Excellency Mr. John F. Axisa, M.B.E., The High Commissioner for Malta; His Excellency Baron Jean van den Bosch, The Belgian Ambassador, His Excellency Mr. A. P. Rajah, The High Commissioner for Singapore; His Excellency Senhor A. L. de Faria, The Portuguese Ambassador; William T. Rodgers, Esq., M.P. Minister of State, Board of Trade; Sir Richard Clarke, K.C.B., O.B.E., Permanent Secretary, Ministry of Technology; Vice-Admiral Sir Frank Mason, K.C.B. (Past President); Major-General Sir Leonard Atkinson, K.B.E., B.Sc., President, Institution of Electronic and Radio Engineers; Sir Stewart MacTier, C.B.E., B.A. (Past President); Sir Arnold Lindley, D.Sc., President, Institution of Mechanical Engineers; Vice-Admiral R. G. Raper, C.B., Director General, Ships, Ministry of Defence (Navy); Monsieur A. Bothner, Norwegian Consul-General, representing His Excellency The Norwegian Ambassador; Monsieur M. J. R. Gaechter, First Secretary, representing His Excellency The Swiss Ambassador; P. C. M. Sedgwick, Esq., C.M.G., Director, The Hong Kong Government Office: Rear-Admiral B. D. Yashin, Soviet Naval Attaché, representing His Excellency The Soviet Ambassador; F. E. Hill, Esq., President, Chamber of Shipping of the United Kingdom; R. A. Huskisson, Esq., Chairman, British Shipping Federation; R. F. Prosser, Esq., M.C., Under-Secretary (Marine Division), Board of Trade; Captain L. W. L. Argles, C.B.E., D.S.C., R.N., Merchant Navy College; Captain J. Baird, C.B.E., Master, The Honourable Company of Master Mariners; Ir. A. C. H. Borsboom, Institute Silver Medallist 1968; R. N. Bruce, Esq., President, Institution of Gas Engineers; J. Calderwood, Esq., M.Sc., (Honorary Member); The Reverend L. E. M. Claxton, M.C., M.A., Rector, St. Olave's Hart Street, London, E.C.3; Dr. A. R. Collins, President, Institution of Structural Engineers; R. Cook, Esq., M.Sc., Honorary Treasurer: W. A. Easton, Esq., M.A., President, Association of Teachers in Technical Institutions; A. Emerson, Esq., B.Sc., Denny Gold Medallist 1968; R. N. Frith, Esq., President, Diesel Engineers and Users Association; Stewart Hogg, Esq., O.B.E., Past Chairman, Social Events Committee; Ir. A. G. Hop, Institute Silver Medallist 1968; L. J. H. Horner, Esq., O.B.E., Director, Chamber of Shipping of the United Kingdom; G. G. Howard, Esq., Joint Managing Secretary, Salvage Association; Dr. R. Hurst, G.M., Director of Research, British Ship Research Association; Dr. D. M. A. Leggett, M.A., Vice-Chancellor, University of Surrey; A. J. Marr, Esq., C.B.E., President, The British Ship Research Association; T. C. Niccol, Esq., B.Sc., President, Society of Consulting Marine Engineers and Ship Surveyors; W. S. Paulin, Esq., President, North East Coast Institution of Engineers and Shipbuilders; S. W. Potts, Esq., President, Institution of Mining Engineers; C. C. Pounder, Esq. (Past President); F. W. van Deelen Esq., Institute Silver Medallist 1968; G. Yellowley, Esq., Chairman, The National Association of Marine Enginebuilders.

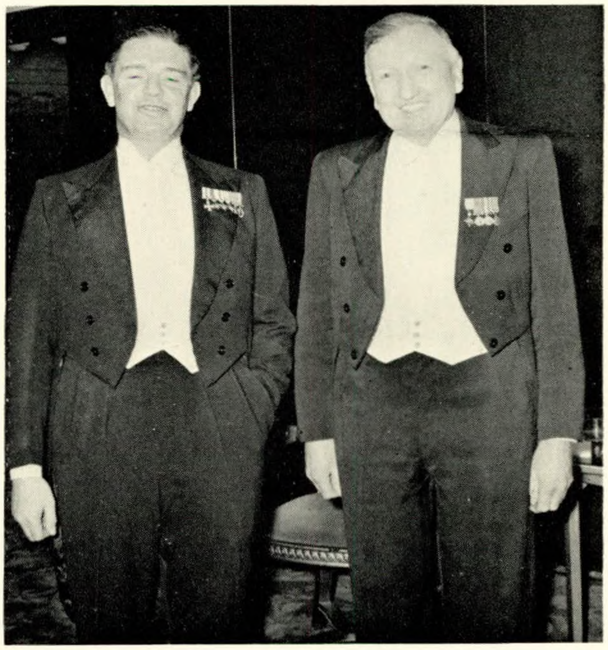
The Loyal toasts having been duly honoured:

HIS EXCELLENCY MR. JOHN F. AXISA, M.B.E., The High Commissioner for Malta, proposed the toast of the Royal and Merchant Navies of the British Commonwealth.

He said: A translation of an old Italian saying goes like this: "It is like the Arab girl, everybody says she is there, but nobody knows where." Proposing the toast to the Royal Navy, I who come from Malta, am conscious of the fact that there is a void in our harbours. Everybody says, "There is still a Royal Navy?" But we in Malta no longer see the Royal Navy. However, we do have the assurance that the Royal Navy is still a powerful force in the Mediterranean; not only that but the Royal Navy units are believed to be today second to none in their effectiveness, in the light of the technological advance which has been made.

Ever since Nelson responded to the call of the people of Malta to go to their assistance and help them achieve their freedom, following the brief French occupation in 1880, there started the close attachment between Malta and the Royal Navy which, over a period of 170 years, has grown from strength to strength.

The absence of the ships from our waters today in no way detracts from the warmth of our relationship, and I consider it most appropriate that Malta's representative in



At the Annual Dinner held on Friday, 14th March 1969 at Grosvenor House, London, W.1: The President of the Institute, Mr. F. B. Bolton, M.C. (left), with Captain W. S. C. Jenks, O.B.E., R.N., Chairman of Council.

Annual Dinner 1969

London should have been honoured with the invitation to propose this toast.

The toast is coupled with one of the Merchant Navy. The defence of the British merchant shipping in the Mediterranean, which shipping has always constituted the largest national merchant fleet in any one time in the Mediterranean, was the responsibility of the naval base in Malta. There are equally affectionate ties between the Merchant Navy and Malta. It was the Merchant Navy, with the support of the Royal Navy and the Royal Air Force, that saved Malta from starvation and enabled her to pursue her front line role in the dark days of 1942. It is, therefore, appropriate that I too should so couple the toast, and I do so from the bottom of my heart.

There could be no Royal or Merchant Navy without a dockyard. The Royal Naval Dockyard in Malta was developed on exactly the same lines as the dockyards in this country and we are very proud of the high standard of workmanship achieved therein. Today, the dockyard is more concerned with commercial than navy ship repair. It is holding its own in the Mediterranean in the face of strong competition by other yards, heightened by the reduced demand because of the closure of the Suez Canal. The dockyard remains our largest single industry and is owned entirely by the people of Malta. It is in this field that your Institute of Marine Engineers plays a vital part.

In February of last year your Institute, together with the Royal Institute of Naval Architects, launched a Joint Malta Branch, which is bound to be of tremendous benefit to Malta. You are aware of the progress being made in Malta in industrial development. The oil industry, the ship and small craft industry, and the proposed free port complex involving specialized cargo vessels and feeder vessels has created new prospects for the youth of Malta, who look to your Institute to guide them in filling the new important positions that are being created. There is then the proposed maritime law whereby ship owners will operate their ships from Malta, flying the Maltese flag. This will increase the demand for Maltese crews, including, naturally, marine engineers.

At the inaugural dinner, launching the Joint Branch in Malta, given by your Institute and the Royal Institute of Naval Architects, as I said, in February of last year, Dr. V. Tabone, my Minister of Labour, replied to the Chairman of the Branch in the following terms: "The Government of Malta welcomes, indeed looks forward to, the co-operation of the Joint Branch in this field of marine engineering and naval architecture, co-operation which has become vital to Malta's newly emerging economy. Malta has for centuries had maritime connexions, and the training of the youth in this profession will help them to play a greater and more important role in Malta's society".

There is no doubt that the importance of the Institute to Britain itself has never been greater than now, when this country faces serious competition in shipbuilding. Competition has affected the industry, not through the loss of the primacy which Britain enjoys in the technological field, but through the raising of social standards. This is the challenge facing the Institute in its efforts to promote the scientific and practical development of marine engineering.

In this respect I most heartily join you in warmly welcoming Mr. Wedgwood Benn's statement, published three days ago, that the outlook for the shipbuilding industry is now more promising than for many years, and the deliveries are being effected well ahead of schedule.

The Institute will derive considerable encouragement from this; more specifically the Institute looks to the Royal Navy and the Merchant Navy for support in its efforts to serve the best interests of the two Navies.

On this note I should like to ask the distinguished guests to drink to the Royal Navy and to the Merchant Navy. (*Prolonged applause*)

VICE-ADMIRAL R. G. RAPIER, C.B., Director General, Ships, Ministry of Defence (Navy), in response said:

About a year ago I was invited to speak in an R.A.F. Mess to celebrate the Jubilee of the R.A.F. The instructions that I had were that the history of the R.A.F. was so short, their exploits so well publicized, that 90 second flat would do! I am sorry that neither of the conditions stated on that occasion apply tonight! I will ask you to bear with me for a little longer!

My first pleasant duty is to reply to the toast proposed to the Royal and Merchant Navies of the Commonwealth, and this is rather like trying to reply to a toast to life itself so far as I am concerned, and not only for our generation, but for others before us. I think possibly the first duty of anybody who has read the British press for the past few months is to reassure you that when you come back next year there will still be a Royal Navy and a Merchant Navy. In the confidently expected absence of another defence review for the rest of this year, we still do have something like 140 major warships, and if you add up a few of the smaller ones it gets to something like 200. In fact the fleet support ships also number something like 41, so we are not yet off the map.

This is just the Royal Navy. The Commonwealth Navies, on whose behalf I am also asked to thank you, and this is another great privilege, are a growing force in the world. As to the Merchant Navy, I do not think there is anybody in this room who does not think it is essential to have this part of the British economy and that our age old activity is unlikely to lessen substantially over the years.

So, one comes to looking at the future, on which a number of White Papers have said what exactly is going to happen to the Royal Navy. My part in this is that my Department has got to make it happen in some way, and we are now busy designing cruisers, frigates, destroyers and mine sweepers, and some other ships. The destroyer, with guided missiles and gas turbine propulsion, has already received some publicity. That was when the first order was placed with Vickers some months ago. We are now struggling with what we require for the future frigates to replace the *Leander* class, and we are also struggling with this thing called a cruiser. It has to carry helicopters, and there seem to be rather a lot, and if it has an appearance of a kind of flat upper deck, it is still a cruiser!

One of the great things is how one goes about this in an age of rapidly expanding technology and rapidly expanding management techniques. This is really where I feel that we and the Merchant Navy, in the engineering sphere in particular, require to get together a great deal closer than we possibly have in the past.

We are bombarded with an enormous number of questions asking: "Why do you not do this or that?" We are told about value engineering, life cycle costing, cybernetics and all sorts of things, and one has to pick one's way through them, knowing perfectly well that a wrong decision may end in disaster, possibly by picking on a piece of new technology prematurely; but on the other hand, the prizes are very great indeed.

In 1902, Jackie Fisher wrote to Lord Selbourne and said, "please ensure that the Controller and his men design our ships with all the modern labour-saving devices, regardless of cost, weight or space, in order to reduce the number of men in each ship". And now, 67 years later, we are trying to do just that! This is also part of the Merchant Ship owners' interest.

So, of course we need to get together. In this business of picking one's way among all this advice, which comes regardless of the situation in which you actually find yourself, it is rather like the first words of the whale to Jonah after he had swallowed him. He said, "Why aren't you singing, man?" Jonah replied, "Why should I sing?". The whale said, "everybody sings in whales!" Really, it is in appreciating the the relevance of the situation to what we really need that I think we can do a great deal by getting together more with the Merchant Navy. There are two ways of doing it. One is a greatly increased liaison with the Chamber of Shipping on technical matters, which we have already been increasing over the past three or four years. The other is by means of discussions through the Institute. I feel this very strongly. Perhaps I feel the need to be sure of doing the right thing, because it happens to be on my head for the warships of the future. I am reminded very much of the situation with a clerk in a post office in Montreal, when I was working over there. I complained twice to the postmaster that my mail did not get to the right address. On the second occasion I got a very charming note back saying that he had tracked down the employee responsible, and I would be satisfied he hoped, "to know that he was grossly abused".

I feel that there are a large number of men at sea who indulge in that activity towards the designers! One hopes desperately for the wisdom this time not to incur that particular sort of abuse.

There is one particular hobby-horse which I should like to ride before you for just a moment. I think the Institute could help enormously in opening discussion on the whole business of systems management. We used to have a marine engineering industry which served the shipbuilders. We now have really the whole of British industry involved in marine engineering—or we should have. This includes the whole field of electronics, communications, all the modern controls technology which is part of our business now. Yet, we seem to be a bit slow. It is a great problem, somehow to integrate these fields in the interest of ship design and of building. It needs a lot of co-operation, a lot of patience, I think, and the engaging of interest in the marine engineering problem in a much wider sphere of British industry.

It goes from the very largest sort of systems, like the container ships, involving all sorts of different things, like transport organizations and so on, right down, I think, to the ordinary ship propulsion machinery, which we find it difficult, really to integrate; we find it very difficult to integrate the system into something which one man can be abused for if he does not get it right!

I will now dismount from my hobby-horse and come to the last part of my duty and privilege, and this is to propose the toast to the Institute of Marine Engineers. I have an enormous admiration for the way in which the Institute has come up in the sort of technological stakes in the past few years, and an enormous admiration for the successive Chairmen of Council, the Councils, the Presidents, the Director and Secretary, and his staff, in battling through the great labyrinth of the C.E.I. business, and the raising of standards: the establishment of standards for educational requirements, and so on. It really is in no frivolous way that I will ask you to stand and drink their health in a moment, because we owe an enormous debt to the people who have borne the heat of the day in all these activities. Then, in addition to all that, there is the organization of the IMAS Conference this year.

So, it is with very real admiration for the work of the Institute, and a very real hope for its continued success, that I ask you to rise and drink the toast to the Institute. (*Prolonged applause*).

THE PRESIDENT, in reply said:

Thank you very much indeed Vice-Admiral Raper, for the way you have proposed the toast of the Institute. I was very interested in what you said about the variety of disciplines in engineering involved in marine engineering, because this is clearly one of the things we have got to take very much into account in the future and in our relationships with the other Institutes. Thank you again, very much, for the way you have proposed this toast.

The Annual Dinner of the Institute always provides a President with the largest captive audience of members during the year. I propose tonight however to resist the temptation, how ever hard it may be, to make use of the opportunity and deal now with Institute business. I do this with greater confidence because I am quite sure that every member here intends to come to the Annual General Meeting on 29th April and to express his views then for the benefit of the Institute and Council!

The opportunity is too good, however, to miss entirely and I do want to make one point. It is very curious, how, although you do not have to tell the public today what an engineer is, you can so easily get completely the wrong impression from the dictionary and from literature. Reference books are only too keen to point to the original military meaning of the word. It is not only that Shakespeare talked of an engineer being hoist up with his own petard, but 175 years later, say 125 years ago, the public would still have thought it was more likely for this to happen—assuming they knew what petard was—than that he would get caught in his own machinery. And even now, there is not very much mention of any sort of engineer in literature. McAndrew is probably the only marine engineer in poetry (or verse) and most of Kipling's other engineers were civil, the builders of India's railways and roads.

Even today there is a bit of shying away from the word "engineer". Why do we always hear about "scientists" at Cape Kennedy, and Russian "scientists" who are building the space craft and missiles? Does a scientist build and an engineer tend? I should have thought that all those "scientists" are engineering trained—are engineers even though they may be scientists as well. But I think all too often the public seem to think that it is management who decide what to do with the machines, the accountants who tells management not to, the scientist who makes the machines and, as in America, the engineer is only the man who drives the train. Against this background it is no wonder that there is a shortage of boys and even more of girls who want to become engineers at all.

This is where the engineering institutions come in. A very large part of their responsibilities is to improve the image, improve the public impression of engineers and improve their status, and thus increase the attraction of the profession to young men. Why do they want to come in at all? Partly I suppose bacause engineering attracts them for its own sake and because it offers attractive prospects. But it is surely one of the major problems of today to try and decide what else motivates people. If we knew more about what makes people work or not work and what makes them take one job or profession rather than another, we should be a long way towards solving many of the problems of this country today.

It is perfectly possible to buy pompous books which set out in a wealth of wholly anachronistic detail the order of precedence of one dignitary over another—who comes in to a banquet on whose arm. This sort of order of precedence has very little meaning today, but what is important is the order of precedence established by public, by common, consent in respect of jobs, positions, professions and callings. If "God Bless the Squire and his relations and keep us in our proper stations" is wholly out of date—and no one would today sacrifice anything to become a squire—how many of the young would sacrifice everything to become a pop singer?

If you want to see youth coming into the engineering profession, surely the task of the engineering institutions is to consider what is needed to make the profession "Top of the Pops", to make it everyone's favourite buy. Each Institute has of course a slightly different set of problems from the others. And this of course brings us back to our own Institute. If there are 18 000 members, it must be run by a smaller inner caucus, the Council. But it is not virile if there is not a constant and continuing participation and expression of view of all members to the Council, direct or through the Branches. The Institute belongs to its members; the members themselves are the best spreaders of the Gospel to budding new entrants and it is the members themselves who can do most to see that we have more coming in than going out each year and not just a narrow balance as in 1968. The Institute is virile if members take part in its activities—and attendances at the technical evening sessions have been falling recently—or express views as to what changes they would like to see. It is the Council's sometimes difficult task to judge between conflicting views put up to them by members. Member participation will make sure that the Institute is alive and up to date and not only growing in membership and quality of technical work, but in interest generated and thus help to improve marine engineering's position in the "Top Ten" of attractiveness as a career.

We cannot tell what will be the pattern of technical development in the future. We can only prepare ourselves to give the best service possible to the marine engineering profession in the confidence that marine engineers will always be wanted. It is in this spirit that, if I may be forgiven for once again breaking into verse, I would offer you the following jingle:

I dreamt that I lived in 2010
Surrounded by triumphs of art, and of men,
But from what I could see it was only to clear
That the country had got no Marine Engineer

For Hovercraft carried containers at sea,
On certificates issued by the ARB
And so Aeronautics could claim with a sneer,
"Just what is the use of a Marine Engineer"?

As oil went from down pipelines then so did the grain,
And the loss to the ships was the Structurals' gain,
No steel, so no ore, and the Chemicals cheer,
For Plastics don't need a Marine Engineer.

The Gas Boys were happy on natural gas,
And so everyone who would want coal was an ass,
The Civils built tunnels but not one single pier,
For there wasn't a ship for the Marine Engineer.

I woke up screaming but quickly got over my fright
As I realized, thank God, that it must be all right.
For as shipping and shipbuilding can't disappear
We must always have a Marine Engineer.

(*Prolonged applause*)

Marine Engineering and Shipbuilding Abstracts

No. 7, July 1969

* Patent Specification.

New Passenger Ferry for Copenhagen/Oslo Route

The first of the two new passenger/car vessels ordered from Cantieri del Tirreno e Riuniti at Riva Trigosa, Italy, for the United Steamship Co. of Copenhagen (DFDS), has entered service on the Copenhagen-Oslo route.

Principal particulars are:

Length, o.a.	406 ft 3 in
Length, b.p.	353 ft 7 in
Breadth, moulded	62 ft 6 in
Depth to saloon deck	56 ft 5 in
Depth to car deck	23 ft 4 in
Draught	16 ft 10 in
Gross tonnage, approx.	7000
Passenger capacity	950
Vehicle capacity, approx.	100 cars
Machinery output	6000 hp at 210 rev/min
Speed	20·5 knots
Speed, maximum average on trials	21·0 knots
Cargo capacity	22 073 ft^3

Kong Olav V has been constructed to Bureau Veritas Class I Div 3/3 L.L.I.I., A. and C.P., Ice II (Finnish ice class 1B)—RMC, and the entire forepart of the vessel has been reinforced against ice. The ship has been divided into 10 watertight compartments and the watertight doors can be closed electrically from the wheelhouse. In a similar manner, the vessel has been divided into fire safety zones, separated by remote-controlled fireproof doors.

To avoid discomfort to passengers and damage to vehicles etc., the vessel has been equipped with a set of Italian-built retractable-type Sperry stabilizers. The manoeuvrability of the ship is increased by the installation of a 1000 hp KaMeWa bridge-controlled bow propeller which gives a thrust of about 11 tons to port or starboard.

The propelling machinry in *Kong Olav V* consists of two H.S.M.-turbocharged Burmeister and Wain type 42-VT2BF-90 Diesel engines, each having an output of 6600 hp at 210 rev/min. This 12-cylinder engine is of the B and W crosshead type, and was selected in preference to trunk-piston engines in view of the very limited head room available.

Each engine drives, through Simplex sterntube seals, an Ansaldo four-bladed bronze propeller having a diameter of 3400 mm and a pitch of 3374 mm.—*Shipping World and Shipbuilder, September 1968, Vol. 161, pp. 1494–1497.*

Largest Swedish-built Oil Tanker

The first of the two 120 300 dwt oil tankers ordered from AB Götaverken by the Samyang Navigation Co. Ltd., of Seoul, Korea, has been delivered. This vessel was named *Sea Star*.

She is powered by a Götaverken 11-cylinder Diesel engine of 850 mm bore and a piston stroke of 1700 mm. This engine has a maximum continuous rating of 26 400 shp at 119 rev/min at an indicated mean pressure of 10·7 kg/cm^2, and has been designed to operate on heavy fuel having a viscosity of 3500 sec Redwood No. 1 at 100°F. It is coupled to a Lips six-bladed propeller of 6650 mm diameter and 5192 mm pitch at 0·7 R. This engine has the highest output of any Götaverken Diesel yet built. By modifying the combustion chamber an even higher output could be obtained.

In addition to normal control from the engine room, a bridge control system has been installed.

Cargo handling is carried out by means of four A.E.G. steam turbine-driven Worthington pumps, each having a capacity of 2500 ton/h (water). These pumps and turbines are vertically mounted.

Steam for cargo oil pump turbines, tank heating coils and other purposes is generated in two oil-fired Götaverken-Babcock and Wilcox watertube boilers each rated at 30 ton/h of steam at a working pressure of 180 lb/in^2. Combustion control is semi-automatic. At sea, steam for fuel heating, turbo-alternator and other services is generated in a Götaverken type combined exhaust gas and silencer unit having a heating surface of 700 m^2.

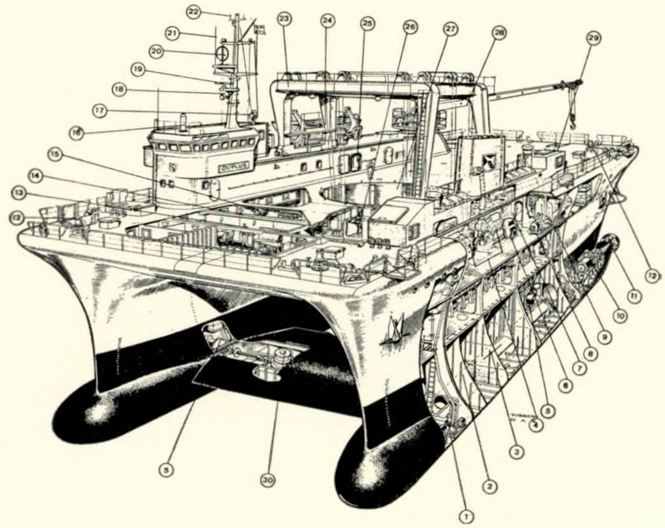
Principal particulars are:

Length, o.a.	893 ft 6 in
Length, b.p.	847 ft 3 in
Breadth, moulded	127 ft 9 in
Depth, moulded	71 ft 8 in
Draught, summer	53 ft 5 in
Block coefficient	0·85
Deadweight	120 300 tons
Gross tonnage	63 988·54
Cargo capacity	4 986 493 ft^3
Ballast capacity	698 865 ft^3
Speed, loaded	16·4 knots

—*Shipping World and Shipbuilder, December 1968, Vol. 161, pp. 1935–1942.*

Twin-hull Sea bed Exploration Vessel

The tremendous rate of increase in exploration of the sea bed—including the undersea search for oil, gas and minerals — has resulted in the development of many specialized vessels in recent years, one of particular interest being the twin-hulled sea bed exploration and service vessel *Duplus*.



1) pump room
2) ballast tank
3) fuel tanks
4) main engines
5) driving motor for v.s. propeller
6) main generator
7) switchboard
8) auxiliary Diesel generator
9) steam generator
10) main propulsion motor
11) c.p. propeller in nozzle
12) capstan
13) crew's messroom
14) laboratory
15) constant tension winch
16) magnetic compass
17) searchlight
18) foghorn
19) radar scanner
20) direction finder
21) Decca aerials
22) Decca Hi-fix aerials
23) gantry crane
24) lifeboat
25) diving centre
26) inclinometer
27) centre well
28) jib crane
29) main winch
30) Voith-Schneider propeller

Artist's impression of Duplus

Built by Boele's Scheepswerven en Machinenfabriek N.V., Bolnes, Holland, to the order of Nederlandse Mij. Voor Werken Buitengaats N.V.—Netherlands Offshore Co.—*Duplus* was designed by J. J. Stenger, a consultant naval architect.

Principal particulars are:

Length, o.a.	131 ft 0 in
Beam	56 ft 0 in
Depth, moulded	36 ft 0 in
Draught	17 ft 0 in
Speed	8 knots

The design of the vessel is based on the fact that submarines at periscope depth possess a high degree of stability. Thus the vessel derives its buoyancy mainly from two submerged, submarine-type hulls. These hulls each carry a slender superstructure which results in minimum waterline area and which are connected together at their upper ends by a wide, flat working deck. To strengthen the whole structure two hydrofoil sections connect the submarine hulls below the waterline. Furthermore, these hydrofoils are also said to have a marked dampening effect on pitch and heave movements of the vessel.

With this special design it will be possible for *Duplus* to work at any depth and, apart from being an excellent berth as a drilling platform, the vessel also has very good navigational qualities. It is capable of running with the sea without using its propulsion motors—the rougher the sea, the faster the speed. Tests are already being made with larger multi-purpose double-hull vessels with the view to this type being used for the transport of containers since both pitching and rolling can be kept to about 2–3° against a conventional ship's movement of 15–20°. It could also be used as a roll-on/roll-off ship.—*Motor Ship, December 1968, Vol. 49, pp. 432–433.*

Fast Cargo Liner

The 13 894 dwt cargo liner *Straat Accra* was built to Lloyd's Register highest class and has tanks for the carriage of edible oil or latex. The vessel has a length overall of 160·76 m (about 527·4 ft), a breadth moulded of 23·0 m (about 75·5 ft), and a summer draught of 10·22 m (about 33·5 ft). A bale capacity of 698 222 ft^3 is given, and there is a refrigerated cargo capacity of 49 301 ft^3.

Following extensive tests in the Netherlands Ship Model Basin, Wageningen, a fine hull form was chosen with a block coefficient of 0·577 at 95 per cent of the summer draught. The midship section is very full and a bulbous stem is not fitted. Ample rudder clearance has been provided by the use of a transom stern.

A long forecastle emphasizes the vessel's fine hull form and ample clear deck space is provided. Hatch Nos 3 and 4 are "open" with three hatches abreast in all the decks. The dimensions of holds Nos 3 and 4 were selected so that the spaces can carry containers of 20 ft by 8 ft by 8 ft stacked five high when the 'tween-deck hatches are open. The arrangement allows 65 containers to be carried in each hold. There is also space for a further 36 containers in hatches Nos 2, 3 and 4 as these have been specially strengthened. A further eight containers can be stowed on the deck space adjoining No. 2 hatch, and there is space for 16 containers in the 'tween decks and in No. 2 lower hold.

Separate insulated cargo hatches are provided so that the four refrigerated compartments in No. 4 hold and those in the No. 5 bridge space can be loaded independently. Lower holds Nos 2, 3 and 4 and the wing spaces of No. 4 'tween deck are specially strengthened for the carriage of heavy cargoes such as ore. No. 2 lower hold has been specially arranged for the carriage of ferro-silicon ore. A duct keel is arranged between the engine room and the palm-oil pump room forward and contains the bilge, ballast, oil-fuel, steam and fresh-water lines.

Cargo-handling equipment consists mainly of cranes, including a Hensen 21·5-ton, twin crane between hatches 3 and 4. The remaining deck cranes are low-pressure Hydraulik/Brattvaag units, ranging in capacity from 3 to 8 tons. The ship is also equipped with one set of 10-ton derricks and a set of 15-ton derricks. Winches and windlass are Hydraulik/Brattvaag units.

The main propulsion machinery consists of a six-cylinder, 13 500 bhp Stork Diesel engine, type SW6, 80/160. At 117 rev/min this engine gives the vessel a speed in service of 20 knots. A four-bladed Lips propeller with a diameter of 5850 mm is fitted. Electrical power requirements are met by four Diesel generators. The engines are 12-cylinder Kromhout vee-type units, each developing 390 bhp at 1800 rev/min.—*Fairplay International Shipping Jnl, 9th January 1969, Vol. 230, p. 45.*

American Container Vessel

American Export Isbrandtsen Line's latest and largest container ship *Sea Witch* is now in regular service between USA and European ports.

Designed by John J. McMullen Associates, and built to ABS class, the principal particulars are:

Length, o.a.	610 ft 0 in (186 m)
Length, b.p.	581 ft 10 in (177·5 m)
Breadth, moulded ...	78 ft 0 in (23·8 m)
Depth, moulded	54 ft 6 in (16·6 m)
Gross measurement, tons...	17 902
Net registration, tons ...	12 898
Deadweight capacity, tons	16 343
Container capacity (hold and deck) ...	928 standard 20 ft units, or 345 × 40 ft and 235 × 20 ft units

Of all-welded construction, the design incorporates a bulbous bow and transom stem, with four holds forward and one aft of the machinery space, each fitted out to accommodate 40 ft containers (for which size there is an increasing demand), although the cells can take the standard 20 ft unit. Provision is also made for deck stowage in two tiers. Refrigerated containers are carried on deck for which 55 points are available.

Propelling machinery consists of a 17 500 shp set of General Electric MST-13 double reduction geared turbines, taking steam at 85 lb/in^2 and 950°F from two Babcock and Wilcox boilers, and driving a five-bladed Baldwin-Lima-Hamilton propeller to give a service speed of 20 knots. Auxiliary power requirements are adequately covered by two General Electric 1250 kW 450-volt, three-phase, 60 c/s turbo-alternators, a 125 kW Diesel generator being provided for emergency use. In common with the majority of modern merchant ships, a considerable amount of automatic and remote control equipment, also of GE manufacture, is installed including bridge control of the main engines. Other features included a Flume stabilization system, and an 800 bhp bow thrust unit.—*Marine Engineer and Naval Architect, January 1969, Vol. 92, p. 20.*

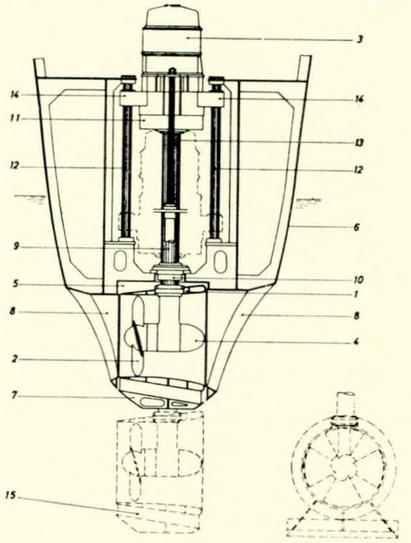
Rotatable and Retractable Bow Thruster

Ships such as research vessels, cable layers and supply vessels frequently require a high degree of manoeuvrability when operating on high seas at very low speeds or when stopped. This is necessary in order to maintain a static position over a point on the sea bed. To assist in obtaining the required manoeuvring characteristics these vessels are often equipped with the Pleuger active rudder, or a bow thruster, and in many cases both active rudder and bow thruster.

In order to maintain adequate submergence in adverse sea conditions bow thrusters of a special type have been developed by Pleuger Unterwasserpumpen G.m.b.H., Hamburg.

The retractable and rotatable bow thruster is housed inside the vessel when it is not required for use, and is lowered through the hull to project beneath the keel when required for operation. When in the working position it can be turned through 360 degrees and is able to direct its thrust in any required direction. These units can be supplied with either a fixed-pitch propeller or alternatively a fully controllable-pitch propeller.

The retractable and rotatable thruster's effect in operation is similar to a Pleuger active rudder installed in a ship with a helm angle of 90-0-90 degrees with the exception that the thruster gives the operator full control over positioning the bow of the ship, the active rudder having more control over the ship's stern.



1) Thrust nozzle
2) Propeller
3) Propulsion unit
4) Gear housing
5) Tunnel recess
6) Ship's hull
7) Bottom section
8) Tunnel opening
9) Rotatable column
10) Lower bearing
11) Crosshead
12) Guide column
13) Piston rod
14) Guide
15) Spaces between ribs

Retractable Pleuger unit

Often research vessels and cable layers, etc., have to work close inshore in shallow water. In these circumstances it may not be considered prudent to lower a retractable thruster. Previously this would have resulted in the loss of the benefits of the installation. However, Pleuger have now improved their existing designs so that a variation of the unit can be offered in such a form that when in the retracted position it becomes a conventional tunnel bow thruster, and thus the installation can be used in shallow water and for general harbour manoeuvres.

In the retracted position this unit can be used as a conventional bow thruster with a controllable-pitch propeller. In the extended position, the unit is used as a 360 degree rotatable propulsion unit with controllable-pitch propeller. With a 450-hp prime mover the unit, when used as a bow thruster, will develop a thrust of 5·5 tons, and in the extended position as a 360 degree rotatable propulsion unit gives a thrust of 6·25 tons.

The principal features of the unit can be seen from the accompanying illustration.

The prime mover for the controllable-pitch propeller is an a.c. induction motor mounted on the crosshead. The drive shaft is driven through a flexible coupling designed to accommodate a radial misalignment of the two shafts of 0·1 mm and an angular misalignment of 1 : 2·500 mm. The coupling incorporates oil resistant rubber blocks which as well as transmitting the drive, also act as shock absorbers in the rotational plane.—*Shipping World and Shipbuilder, April 1969, Vol. 162, p. 564.*

Norwegian Computer System for Ships

Automation experts from Det norske Veritas, the systems engineering company Noratom-Norcontrol, the Engineering Research Foundation at the Technical University of Norway and the Ship Technical Research Association, have co-operated on a project to install a computer system on board a Norwegian ship in order to test its technical and operational functions and to assess the economic aspects connected with the use of a computer afloat.

Wilh. Wilhelmsen has agreed on the installation of a computer system on board one of their liners which is now under construction. The project has progressed so far that the specifications have been decided upon, all components ordered and a Norwegian-made computer delivered. Details of the project are now being worked out and programmes for the computer are being made and tested.

Work on the project began in the autumn of 1966, and the trial installation will be fitted on board during the first six months of 1969. The trial period will last at least a year.

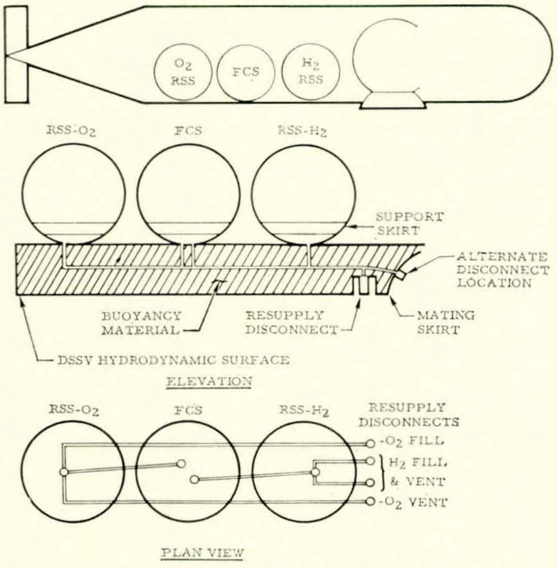
The computer system will be programmed to cover the following functions on board:

1) complete alarm and monitoring system which will comply with Det norske Veritas' requirement for the E0 class (periodically unmanned engine room). During the programming of the system, stress has been laid upon achieving certain advantages which are difficult to attain with normal instrumentation;
2) complete system for control and monitoring of the electricity supply;
3) system for performance control of the main engine and the hull and for automatic reporting of data from the machinery;
4) system of anti-collision supervision by which a computer processes data from the radar installation covering automatic tracking, automatic plotting of velocity vectors and warning of collision danger;
5) programme or calibration in connexion with cargo distribution which will be of help to the cargo officer in reducing loading/unloading time;
6) programme for administrative data handling on board, including calculation of wages, with copies of the necessary reports and instructions in this connexion.

—*Shipbuilding and Shipping Record, 20th/27th December 1968, Vol. 112, p. 817.*

Power Generation for Advanced Submersibles

Contemporary undersea vehicles are limited to operation near the ocean surface for relatively short time periods. Over 80 per cent of the ocean floor is still beyond the reach of man for efficient search, exploration, or object recovery. One prime reason for this situation has been the excessive weight of vehicle equipments, and the corresponding need for massive quantities of buoyancy material. A second major limitation has been the necessity for returning to the surface between missions. Rough seas drastically limit the efficiency and safety of current submersibles by interfering with replenishment and battery recharging operations.



Typical power installation for the DSSV

The U.S. Navy is currently developing an advanced vehicle, the DSSV, which will provide a significant extension in submersible technology. The vessel will be capable of reaching 97 per cent of the ocean floor and will operate at these depths for over 30 hours—three times the endurance of current submersibles. Although DSSV incorporates many technological advances to achieve this capability, one of the most significant is the selection of a fuel cell power system in place of conventional batteries. This provides higher peak power capability and increased endurance at a much lower weight penalty.

The technological base for one candidate fuel cell, the hydrogen/oxygen system, has already been developed in the manned aerospace programmes. This system consumes hydrogen and oxygen to produce electrical power, heat, and water. The latter provides a clue to perhaps the most significant advantage of this system: the submersible powered by a hydrogen/oxygen fuel cell is operating in an unlimited supply of potential reactants.

The operational fuel cell power system (FCPS) consists of three major equipment groups: the power production sub-system (PPS), the reactants supply sub-system (RSS), and the reactants resupply module (RRM). The first two are installed in the DSSV and are semi-permanently connected by reactants piping. The RRM is mounted on the deck of the support vehicle and connected to the RSS by remotely actuated disconnects. The three sub-systems also have two operational modes. During a DSSV sortie the PPS and RSS operate as a fluid transfer system, while the RRM is isolated and in the standby mode. During DSSV replenishment, the RSS and RRM operate as the fluid transfer system. The PPS is isolated by shut-off valves and in the standby condition.

The PPS consumes high purity, low pressure (below 50 lb/in^2abs), gaseous reactants in direct proportion to power demand. It operates in a one atmosphere environment, and is therefore housed in its own pressure shell. Water produced by the PPS is at low pressure and must be stored within this containment until completion of the mission. Other storage requirements include inerts or other impurities introduced into the PPS wtih make-up reactants, plus the purge reactants used to remove them.

The reactants supply sub-system (RSS) stores hydrogen and oxygen outside the fuel cell containment and delivers it to the PPS on demand. The RSS includes separate controls, piping, and storage vessels for each reactant. Thus, there is no possibility of mixing reactants except in the PPS itself.—*Donaldson, G. B., UST (Undersea Technology), December 1968, Vol. 9, pp. 32–33; 39.*

Non-cellular Short-sea Container Ship

To cellularize or not to cellularize is a decision which faces many existing and potential operators of short-sea container services. The problem is confined to short-sea routes, as the larger ocean-going container ships now entering service stack containers at least three tiers high in the holds and in most cases five or more—an arrangement which at the present stage of development necessitates an internal cellular structure.

One company which has, for the time being, decided to employ non-cellular ships on an all-container service is European Unit Routes Ltd. (EUR).

Impala, has been specially tailored to carry 63 20-ft, I.S.O.-type, containers. Of 1500 dwt, the ship is on long-term charter from Peter Döhle of Hamburg and was built at the Hamburg yard of J. J. Sietas.

The most interesting feature of the ship is, therefore, the container-locating and restraining fittings which, in conjunction with a predetermined hatch width, have made a fairly standard ship suitable for the carriage of containers without fitting a cellular structure.

Principal particulars are:

Length, o.a.	242 ft 9 in
Length, b.p.	222 ft 0 in
Breadth	35 ft 6 in
Depth	20 ft 0 in
Draught	12 ft 11 in
Container capacity	63 × 20-ft units
Cubic capacity—	
grain	85 700 ft^3
bale	76 300 ft^3
Bunker capacity	111 tons
Complement	8 men

The vessel has a single hold in which containers are stowed two-tiers high and three abreast in rows of six (20-ft units). This arrangement gives a total of 36 20-ft units below deck, the aftermost row being raised 16 in above the tank top to allow three-wide stowage: the hull lines are, of course, those of a standard vessel and not specially drawn to provide a rectangular hold bottom.—*The Motor Ship, November 1968, Vol. 49, pp. 385–388.*

Maierform SV Bow

The 71 000 dwt motor tanker *Fernmanor*, built in 1964 by Ishikawajima-Harima Heavy Industries for Fearnley and Eger of Oslo, has recently been fitted with a Maierform SV bulbous bow. In its original form the vessel had a fully loaded speed of about 16·5 knots and when in the ballast condition, a speed of about 17·5 knots when the engine was developing 20 700 bhp.

By 1966 the owners recognized the need for an improvement in speed in order for the vessel to remain competitive. Investigations of different possibilities of improving the speed were carried out and information from Japan showed that by converting the forebody and incorporating a bulbous bow it would be possible to increase the speed in the ballast condition by almost a knot. Fearnley and Eger place an order with Maierform S.A. of Geneva, to develop the optimum SV bow for *Fernmanor* by systematic tank tests using self-propelled models. The results of these tests, showed that there was an improvement in speed of 0·8 knots in ballast and 0·53 knots fully loaded. Furthermore, when compared with results of the non-converted old form of hull, the vessel with the SV bow shows savings in power and fuel consumption at the same speed, of from 11 to 14 per cent.

The arrangement of the SV bow increased the vessel's displacement by 450 tons and as the weight of the bulbous bow is no more than 130 tons, an additional 320 tons have been added to *Fernmanor*'s deadweight. A further advantage expected is that not only will the vessel's speed be increased in good weather conditions but, as the seakeeping qualities are improved, the loss of speed in adverse weather conditions will be reduced owing to the positions and shape of the V-frames. Compared with the original vessel, the differences in speed under bad weather conditions will be somewhat higher and more favourable than in calm weather conditions.—*Shipbuilding International, March 1969, Vol. 11, pp. 32–33.*

Fastest Diesel-engined Irish Sea Ferry

The fastest Diesel-engined Irish Sea ferry was recently launched from the Ronsburg yard of Werft Nobiskrug, G.m.b.H., for British and Irish Steam Packet Co., of Dublin (B. and I.). Named *Innisfallen*, the new 24-knot roll-on/roll-off ship will be very similar to the "Leinster" also launched recently for B. and I. Line except that *Innisfallen* is to have more powerful main machinery. The main engines will comprise four M.A.N., seven-cylinder, RV 40/54 medium-speed machines coupled in pairs to twin-screws. The engines are designed for a combined total output of 16 000 bhp when running at 428 rev/min and will transmit this power to the propellers through reduction gearboxes to give a propeller speed of 250 rev/min.

Principal particulars of *Innisfallen* are as follows:

Length, o.a.	387 ft 8 in
Length, b.p.	353 ft 8 in
Beam at car deck	57 ft 9 in
Depth to prom. deck	36 ft 9 in
Draught	14 ft 9 in
Deadweight (approximately)	1000 tons
Gross register (approximately)	4800 tons
Trials speed	24 knots

An off-centre engine room casing in the garage area will allow sufficient headroom for the through passage of heavy vehicles, while hinged swing decks will provide the additional car capacity: access to these spaces will be through bow and stern doors. In the passenger accommodation air-conditioning is arranged throughout.—*The Motor Ship, February 1969, Vol. 49, p. 558.*

9000 hp Deep Sea Tug

The largest tug in the Dutch fleet is the recently completed 9000 ihp *Rode Zee*, owned by L. Smit and Co's. Internationale Sleepdienst, Rotterdam. Not only is the 68·5 m vessel the most powerful Dutch tug, but she is also the first ship to be propelled by the Diesel engines of the new TM 410 design of Werkspoor N.V.

Principal particulars:

Length, o.a.	68·50 m
Length, b.p.	62·00 m
Breadth, extreme	12·62 m
Breadth, moulded	12·10 m
Depth, moulded at 0.5 length b.p.	6·40 m
Designed draught at 0·5 length b.p.	5·50 m
Summer draught at 0·5 length b.p.	5·74
Gross tonnage	1311·62
Classification	Lloyd's Register ✠ 100 A1 Tug

Built by N.V. Scheepswerf en Machinefabriek De Merwede at Hardinxveld-Giessendam, Holland, 1311·62 gross ton *Rode Zee* has been specially designed for the towage over long distances of such heavy objects as drilling rigs and for rendering assistance to the larger classes of tanker and bulk carrier.

For such duties, a high bollard pull is required: therefore the tug has a Lips c.p. four-bladed, 4000 mm-diameter propeller, operating within a nozzle. This single propeller is driven by two Werkspoor TM410 six-cylinder/four-stroke, turbocharged engines of 9000 ihp combined output at 500 rev/min, which transmit through Vulcan fluid couplings and A.G. Weser reduction gear.

Tests were carried out by the Netherlands Ship Model Basin at Wageningen to determine the most favourable pitch for various propeller loads. To obtain the best nozzle efficiency special attention was paid to the form of the stern. Two spade-type rudders are fitted abaft the nozzle: it was difficult to apply normal balanced rudders because of the high rudder forces which had then to be absorbed by the nozzle.

Control of the towing winch is from a room situated above the winch, ensuring a good view of the drums and after deck. The towing winch by Werktuingen van der Giessen, has two drums, each to take 1000 m of steel hawser of 7¼ in and 6½ in respectively. The towing gear also comprises three spare towing wire ropes, each of 1000 m, two of which are 7½ in circumference and one of 6½ in circumference.—*The Motor Ship, February 1969, Vol. 49, pp. 552–553.*

Largest South African-built Cargo Vessel

The 314-ft m.v. *Tugela* completed by Barens Shipbuilding and Engineering Corporation Ltd., Durban, and delivered to her owners Unicorn Shipping Lines (Pty.) Ltd., Durban, holds pride of place as the largest and first of three cargo vessels to be constructed in the Republic of South Africa.

The vessel, built to the requirements of Lloyd's Register of Shipping Class ✠ 100 A1, is of all welded construction throughout with longitudinal framing in way of the bottom and main deck, and transverse framing within the cargo space. The main deck hatch openings are fitted with MacGregor single pull electrically operated steel covers arranged for sectional opening to give quick control for working cargo when the weather conditions are variable. A side-port opening fitted with a MacGregor closing appliance is located in the vessel's side shell plating.

Principal particulars are:

Length, o.a.	314 ft 0 in
Length, b.p.	292 ft 4 in
Breadth, moulded	47 ft 6 in
Depth to upper deck	26 ft 8 in
Draught to tonnage mark ...	21 ft $6\frac{1}{4}$ in
Draught to freeboard mark ...	18 ft $8\frac{3}{4}$ in
Deadweight to tonnage mark ...	3500 tons
Deadweight to freeboard mark...	4500 tons
Cargo holds capacity—bale ...	200 000 ft^3
Speed at freeboard mark ...	13·50 knots
Main engine output	3000 bhp

Within the vessel everything possible has been arranged for the use of mechanical equipment there being two holds and 'tween deck being served by three hatchways.

Propulsion machinery consists of turbocharged six-cylinder Sulzer type RD.44 direct reversible oil engine working on the two-stroke cycle principle with airless fuel injection. This engine is designed to develop 3000 bhp when running at 215 rev/min normal rating output and is directly coupled to a single screw shaft driving a three-bladed Zeise Alcunis propeller.

The choice of engine was made after careful consideration of the available servicing arrangements in South Africa, the specific operational service of the vessel and the owners' own home-based maintenance facilities.

The main engine is arranged to operate on a blended type fuel of 150 sec Redwood No. 1. The limited amount of fuel being consumed during service was the deciding factor against heavy fuel, and once this decision was arrived at, so boilers with their attendant expenses of maintenance and staff, were eliminated. To arrive at the blended fuel, consideration was given to the available heat recoverable from the engine cooling system, and by utilizing this heat through a special Serck unit, the viscosity demanded at the fuel pump for efficient atomization is achieved.

Trials were carried out off the Natal Coast in the Durban Bay and, as there is no measured mile for analysis of speed, these trials were carried out using Telemetaniqe equipment supplied and operated by the South African National Physical Research Laboratory. This equipment has been developed by this organization and operates on the instantaneous readings of cross bearings from fixed shore bases —accuracy is guaranteed to 0·5 per cent.

Speed trials were run at 60 per cent, 80 per cent and 100 per cent power over distances of 15 miles in each direction and from the curves plotted against the Model Basin prediction, the results are most satisfactory. The rev/min for developed power being attributable to the slightly lighter pitch of the propeller as fitted, against the original design of the Model Basin.—*Shipbuilding and Shipping Record, 14th March 1969, Vol. 113, pp. 362–365.*

Finnish Icebreaker

The Oy Wärtsilä Ab Helsinki shipyard has recently delivered the 12 000 shp icebreaker *Varma* to the Finnish Board of Navigation.

In principle the *Varma* is of the same type as the *Tarmo* which was delivered by Wärtsilä in 1963 but its length has been increased by 6 ft 7 in (2 m). This lengthening follows intensive research work and model tests which have shown that the rudder can be more advantageously positioned with respect to the propellers. As a result of this the steering characteristics of the icebreaker have been improved to such an extent that in certain cases the steering power has even been doubled.

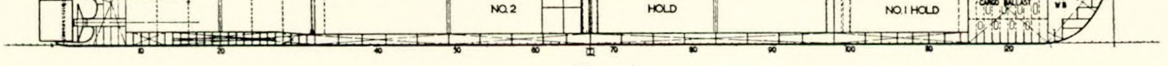
A high degree of automation and remote control facilities have been applied to the vessel's machinery and it is the first Finnish icebreaker to be equipped with a data logger. This unit scans 256 points. The main machinery comprises four Sulzer 8MH51 Diesel engines each having an output of 3440 hp at 365 rev/min and built by Wärtsilä's Turku shipyard.

Principal particulars are:

Length	283 ft 10 in
Breadth	69 ft 7 in
Draught	20 ft 4 in
Normal displacement about ...	5000 tons
Speed in open water	18 knots

The main Diesel engines are each connected to a double armature d.c. generator. These feed four double armature d.c. propulsion motors, located two at the stern and two at the bow. The stern motors each develop 1700 kW at 150 rev/min while those at the bow each develop 1100 kW at 190 rev/min. Oy Strömberg Ab, who supplied the electrical equipment have replaced the rotating converters with thyristor bridges and the regulating arrangement of the entire propulsion machinery with electronic regulation.

Another feature incorporated, which is characteristic for an icebreaker, is the provision of heeling tanks to prevent the vessel from getting jammed in difficult ice. In the system, two pumps can transfer 270 tons of water from one side to the other in 35 seconds, this system being automatically controlled and is operated from the wheelhouse.—*Shipbuilding International, March 1969, Vol. 11, pp. 24–25.*

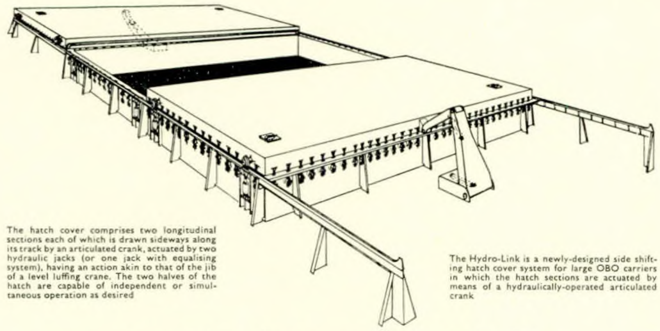


m.v. Tugela

Side Shifting Hatch Cover for Obo Ships

OBO carriers are a rapidly growing class of vessel, and one in which hatch covers feature largely and have, in fact, posed a number of problems. Not the least of these concerns a number of explosions, as yet largely unexplained, which have occurred in the cargo spaces of this type of ship.

Theories that the blasts have been due to metal-to-metal contacts causing sparks which have, in turn, ignited gas pockets are not very convincing but, in the absence of other more satisfactory reasons, have had at least to be considered.



The hatch cover comprises two longitudinal sections each of which is drawn sideways along its track by an articulated crank, actuated by two hydraulic jacks (or one jack with equalising system), having an action akin to that of the jib of a level luffing crane. The two halves of the hatch are capable of independent or simultaneous operation as desired

The Hydro-Link is a newly-designed side shifting hatch cover system for large OBO carriers in which the hatch sections are actuated by means of a hydraulically-operated articulated crank

Side shifting hatch cover for OBO ships

To obviate any finger being pointed at the actuating mechanism, Kværner introduced the rack and pinion/operated version of their side-rolling hatch cover. This featured a hydraulic motor mounted on the hatch coaming, with the rack high on the cover—so far from the actual coaming/cover joint that any gas emission would be dispersed long before reaching the area where any spark, emanating from pinion or rack contact, might occur. Possible gas pockets in the cover structure itself are precluded, by Kværner, by closed pontoon construction.

The Hydro-Link system of rolling hatch actuation features a hydraulically-operated articulated crank in which the principal components are standard production hydraulic jacks of the type used in constructional engineering and the resistance of which to environmental conditions is well-proven.—*Shipbuilding and Shipping Record, 14th March 1969, Vol. 113, p. 366.*

New Propeller Steel

With the construction of larger tankers, cavitation erosion damage to and bending of the trailing edge of the propeller blade have become unavoidable even with nickel-aluminium bronze propellers because of aggravated non-uniform flow distribution of water right behind the ship's afterbody and the increase of horse power per shaft. At the same time troubles have become observed in stern tube bearings due to the increased propeller weight so that demand has grown for some stronger and lighter propeller material than nickel-aluminium bronze.

A new stainless-type special steel was developed, which has corrosion fatigue strength in sea water, greater than 40 kg/mm^2, about twice as large as that of nickel-aluminium bronze, and also excellent anti-erosion properties 20 or 30 times that of nickel-aluminium bronze. This material is most suitable for large-sized propellers. By the use of this steel for propellers, advantages are expected as below:

1) lightening of the weight;
2) improvement in propeller open-efficiency;
3) decrease in vibrational troubles by increasing the number of propeller blades and/or by reducing the blade thickness;
4) ease of producing huge propellers (building-up by welding).

Propellers of this material can be cast as a whole but to save machine hours, which are liable to increase due to its high hardness, it is desirable to cast separately each of the blades with top precision and then assemble them into a complete solid propeller by welding under the optimum setting (minimum tolerance) by the use of an electronic computer.

The undesirable characteristics of stainless steel type-materials, susceptibility to pitting corrosion resulting in deterioration of fatigue strength is avoidable by the use of cathodic protection. A propeller of 1·8 m diameter was made of this steel and tested for about one year. From this test it was shown that the effect of cathodic protection at −0·8 V (saturated calomel electrode scale) was perfect.

Trial manufacture of a propeller of 5·7 m diameter by the above-mentioned welding method was carried out with this new special steel and the following results were obtained:

1) Control of chemical composition through melting in an Héroult electric arc furnace is comparatively easy.
2) It is possible to obtain a very sound casting, even in the interior of the massive part.
3) It is presumed that the dimensional deviations concerning pitch, rake and inter-blade angle due to casting, welding and heat treatment can be corrected by taking counter measures against the deviation beforehand at the time of moulding, and by optimum setting in the building-up process; also by adoption of simultaneous welding in the assembly stages.

—*Taniguchi, K., Tanker and Bulk Carrier, January 1969, Vol. 15, pp. 536–538.*

Large General Cargo Freighter

The Alaskan Mail is the forerunner of an entirely new ship design and will soon be followed by four sisterships. These five ships are the world's largest general cargo freighters, being 22 208 dwt.

During the trials the ship proved the validity of her design, when on high-speed runs and economy trials an average speed in excess of 23 knots was attained, fuel consumption rate was below the design figure and the ship was exceptionally free of vibration.

These 605-ft, 31 995-displacement-ton ships are being built for American Mail Line by Newport News Shipbuilding and Dry Dock Company.

Cargo is handled by 70-ton heavy-lift gear located between holds Nos 5 and 6. This cargo gear can serve both of these holds. The other cargo-handling equipment consists of 12 units with 15- and 20-ton capacities.

Macgregor-Comarain, Inc. designed and fabricated the four sets of "Bipod" masts. These masts are completely self-supporting, requiring no stays or shrouds to hamper rigging and cargo-handling operations. The mast legs, of the distinctive "A" frame configuration, also serve as cargo-hold ventilation ducts.

All seven holds are fitted with MacGregor-designed and supplied hydraulically actuated steel-hinged folding hatch covers. The main deck hatch covers are capable of carrying containers, stacked two high. The 'tween deck covers were designed to sustain fork-lift operations.

Provisions have been made for carrying a total of 409 standard 20-ft containers on deck and in the holds. With this number of containers, the Alaskan Mail can still carry approximately 10 000 tons of bulk palletized or breakbulk cargo. Provision has been made to carry up to 60 refrigerated containers on deck.

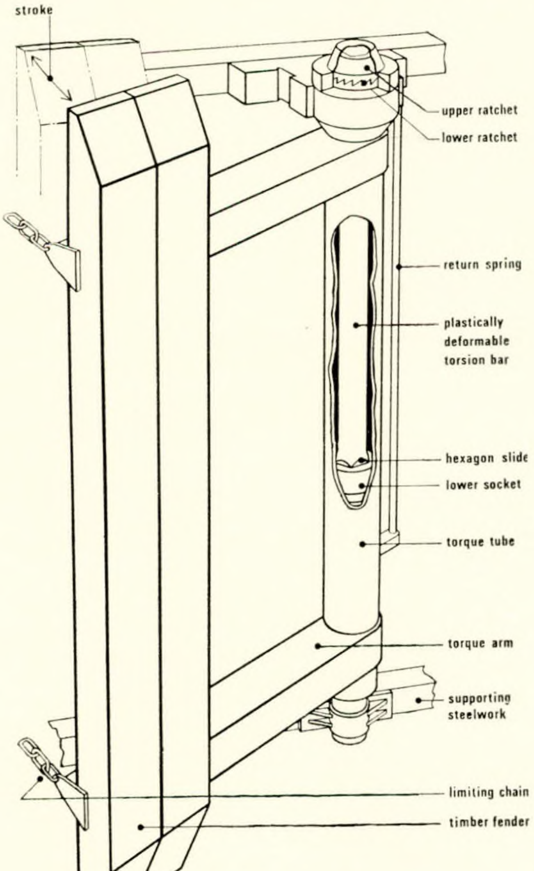
The 24 000 shp, at 105 propeller rev/min propulsion plant is generally arranged as on the highly successful C4 Washington Mail-class. The principal change is the addition of pilot-house control. The engine room length was held at 60 ft and the naval architect has followed his usual practice of having all principal operating equipment positioned so that it is within easy view of the watchstander, giving him complete control over all functions.

Steam is supplied to the turbines at 850lb/in^{2}g, 930°F using a two-heater cycle with steam air heaters and economizers.

The MST-13 propulsion turbines and gears, the turbogenerators, the main switchboard, and the principal electric motors were all manufactured by the General Electric Company. The boilers (two) are Babcock and Wilcox water-cooled-furnace units with vertical superheaters, superheat control, three (each) B and W "American Racer" steam-atomizing burners, and Bailey Meter Company two element combustion controls and feedwater controls. This combustion-control system has been supplemented by a Bailey pneumatic-electric centralized propulsion control system.—*Maritime Reporter/Engineering News, 1st December 1968, Vol. 30, pp. 6, 8, 10.*

Novel Type Fender

The Cambridge fender offers a new solution to the problem of absorbing the kinetic energy of the berthing of large vessels. In any fender there are two fundamental structural elements; the energy-absorbing element; and the mechanism whereby the impact energy of the berthing ship is fed into the energy absorber. These together determine the overall load-deflexion characteristic of the fender. The Cambridge fender, which has been produced and developed by the Cambridge Fender and Engineering Co. Ltd., employs the principles of energy absorption by plastic deformation of metals elucidated by Professor Sir John Baker, head of department, Cambridge University Engineering Laboratories, in a design by Mr. P. W. Turner, senior design engineer, which incorporates a plastically deformable torsion bar.



The Cambridge fender

The impact energy of a ship berthing against any given fender varies widely. The energy to be absorbed in any given impact is unknown, but the mean energy and hence the total energy over, say, the lifetime of the fender is fairly well defined. For this reason an energy absorbing device having a given total energy absorption rather than a fixed single impact absorption is better suited for use in a fender.

Any ductile structure deformed beyond its yield point is such a device. In particular a mild steel torsion bar which, being a solid of revolution, does not change its shape when so deformed and which is capable of a large energy absorption per unit weight of material (up to 100 in tons/lb) is especially appropriate. After wind-up of the torsion bar it is, of course, necessary to reset the fender so that it is ready for the next berthing and this is achieved by mounting a ratchet mechanism at one end of the bar which, when the load is removed from the bar, is caused to overrun, thus setting the system to its original configuration.—*Tanker and Bulk Carrier, March 1969, Vol. 15, pp. 659–660.*

Canadian Fishery Protection and Research Vessel

The Federal Department of Fisheries took delivery late last year of the fishery protection vessel *Tanu* from Yarrows Ltd., Victoria (B.C.). She will be employed on patrol and search and rescue work along the Pacific Coast; and can also undertake research work in connexion with fishing methods for salmon, tuna, halibut, and herring, or general oceanographic work.

Built to the requirements of Lloyd's Register class ✠ 100.A1 the vessel has a long forecastle, raked stem and cruiser stern, and is strengthened for navigation in ice and provided with an ice horn aft to protect the rudder and propeller when manoeuvring astern in an icefield. Below the main deck main propulsion is by two eight-cylinder Fairbanks Morse type 38D8-1/8 Diesel engines, each rated at 1280 bhp at 720 rev/min, and turning a 7 ft 9 in (2·35 m) KaMeWa stainless steel c.p. propeller through Vulcan Sinclair fluid couplings and twin-input/single-output Hindmarch/MWD 2·4:1 reduction gearing. To facilitate manoeuvring, and to maintain while stopped—or proceeding at slow slow—while undertaking research work, auxiliary propulsion is provided by a Pleuger active rudder. This comprises an hydraulically operated c.p. propeller powered by a 125 hp motor, and full bridge control is provided for both main and auxiliary propulsion units.

Electric power at 460 V three-phase 60 Hz is provided by four (one stand-by) 125kW/156·5kVA Westinghouse alternators each powered by a six-cylinder Dorman type QT turbocharged Diesel engine developing 244 bhp at 1200 rev/min.—*Shipbuilding and Shipping Record, 17th January 1969, Vol. 113, pp. 81–84.*

Ocean Research Ship

Robray 1, a new geophysical exploration vessel able to operate in remote, unexplored ocean areas longer and more accurately than previous commercial ships of its type, is now gathering oil-exploration data from the Pacific Ocean floor north west of Australia.

The vessel combines satellite navigation and doppler-effect sonar to determine its geographical location without needing shore-based reference stations, and the array of navigational equipment is said to be the most sophisticated currently available on one ship.

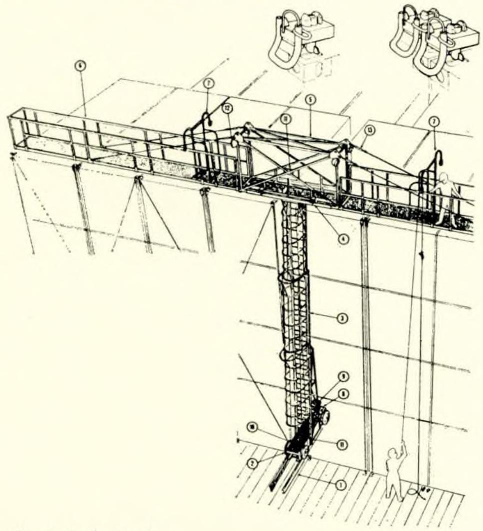
Robray 1 can operate continuously for 50 days without taking on supplies.

The vessel's navigational system uses four orbiting satellites to chart location and course. It can be used anywhere in the world. A pulsed sonar doppler system compares the movement of the vessel with the shift of sonar signals from below, ahead, behind and beside the ship to determine the course between satellite fixes.

With satellite navigation, a ship-board receiver picks up a series of consecutive signals transmitted by the orbiting satellite. The doppler effect indicates the position shift of the successive signals. In repeated test runs, positioning by satellite has been accurate to within about 350 ft.

Data-gathering equipment is among the most advanced available. The ship uses a specially-developed air gun which generates seismic pulse vibrations with underwater blasts of compressed air, instead of conventional dynamite methods. Magnetic tape systems record signals provided by the vibrations and the resulting data can be computer-processed faster and more accurately than data from previous, non-summing recorders.—*Shipping World and Shipbuilder, March 1969, Vol. 162, p. 407.*

Securing Containers Carried on Deck



1) Longitudinal deck track
2) Cart furnished with Tilt Prenting type of roller wheels
3) Support stand and elevating telescopic ladder with shoot safety cages
4) Quick lock connexion for bridge centre section
5) Bridge centre section
6) Hinged bridge extensions with cable suspensions
7) Movable pulley hoisting gears
8) Travelling machinery
9) Elevating cable pulley drive
10) Parking brake
11) Push button controls for travelling and bridge elevation
12) Headlamps
13) Rigged screws for suspension cables

Travelling frame used in the ACL ships to speed the rigging of the lashing wires for securing containers on deck

The container concept is geared to extremely rapid turn round but securing the containers carried on deck is a time consuming job and one which must be done very thoroughly if damage and possible loss overboard is not to be suffered. The method which Atlantic Container Line employ is to use cross-braced tension wires and rigging them calls for expert team work with one party on top of the containers and the other party working on deck. An ingenious device developed by Bromma Smidas (forge) has been used in ships of the A.C.L. fleet which carry containers as much as four high on deck, the two lower layers being loaded and the two upper layers empty. The fitting consists of a four-wheel trolley running on narrow rail tracks extending fore and aft along the centre line of the ship between the two four-wide rows of containers. This has an extendable column supporting a transverse platform with pulleys and tackle. The trolley is power operated, enabling it to move fore and aft and to be elevated under power.—*Svensk Sjofarts Tidning; Marine Engineer and Naval Architect, March 1969, Vol. 92, p. 135.*

Dutch-built LPG Carrier for Dutch Owners

The LPG carrier *Coral Maeandra* which was delivered by Scheepswerf "De Waal", Zaltbommel, to the Koraal Scheepvaart Maatschappij, Curaçao—an affiliated company of Anthony Veder and Co., Rotterdam—is the first Dutch-built, Dutch-owned seagoing vessel for the transport of liquefied petroleum gas under atmospheric pressure. She has been designed for the carriage of hydrocarbon gases such as propane (C_3H_8), n-butane and i-butane (C_4H_{10}), as well as aggressive chemicals with a specific gravity of 1·7. Among the various petroleum products which offer a considerable potential in terms of overseas trade LPG is by far the most important.

Because of the low temperature of the LPG cargo (generally in the range of -10 to -59°C) some special problems occur compared with the same cargo carried under pressure. These include the necessity of using special low-carbon manganese steel for the construction of the cargo tanks and the need for supporting arrangements for free-standing tanks to counteract the thermal movements of the cargo tanks relative to the ship's hull and deformation of the latter at sea. Insulation is required to protect the steel of the ship's hull from the low-temperature cargo, and cargo-handling equipment must be designed for differential expansion. Copper fittings must be avoided if an aggressive cargo like ammonia is carried as copper is attacked by this and will react with it to form highly explosive acetylides.

The advantages to be obtained by the refrigerated-type LPG carrier compared with the pressure-type LPG ship are due to the fact that at low temperature the gas volume is considerably less (1/300th part) than the original volume, while the specific gravity is considerably greater. This makes it possible to ship large bulk consignments economically. Refrigerated gas also makes it possible for the tanks to fit the hull more closely than can the pressure vessels.

Principal particulars are:

Length, o.a.	103·20 m
Length, b.p.	94·00 m
Breadth, moulded	14·80 m
Depth at side	8·30 m
Draught loaded (ammonia cargo)	5·70 m
Cargo tank capacity	4550 m^3
Cargo capacities:	
Propane	2560 tons
Butane	2648 tons
Ammonia (anhydrous) ...	3000 tons
Chemicals	3680 tons
Compressor and pump capacities:	
Loading:	
Ammonia (anhydrous) ...	420 m^3/h
Propane	420 m^3/h
Butane	420 m^3/h
Chemicals	200 m^3/h
Discharging:	
Ammonia (anhydrous) ...	435 m^3/h
Propane	435 m^3/h
Butane	435 m^3/h
Chemicals	195 m^3/h

The cargo-handling installation is relatively extensive owing to the need to incorporate in these ships reliquefaction plant for the evaporating gases. In *Coral Maeandra* this plant consists of three oil free type Sulzer compressors and heat exchangers for reducing the gas temperature. One auxiliary LPG tank is available for cooling down the tanks prior to loading cargo. Two Vapor steam-generators with a total steam production of 6000 kg/h are used for discharging gas in a vapour state to non-refrigerated terminals. The heating plant for which the heat provided by the steam generators is supplied makes it possible to discharge the gas at a temperature of -5°C, while it has a capacity of 120 m^3/h.

Propulsion of *Coral Maeandra* is by a Smit-Bolnes Diesel engine type V320-D, developing 4000 hp at 300 rev/min. This gives the vessel a speed of 14·5 knots.—*Holland Shipbuilding, December 1968, Vol. 17, pp. 48–50.*

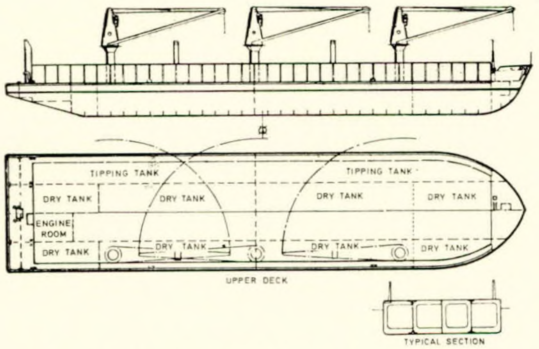
10 000 ton Unmanned Barge

An order for a non-propelled, unmanned, 10 000 dwt barge-type vessel designed to carry heavy cargoes on deck, has been placed with Howaldtswerke-Deutsche Werft at its Kiel yard. The owners, Neptunbolaget of Sweden, intend to employ the vessel to transport pulpwood, on the Swedish short-distance routes.

Main particulars of the design, which was produced in conjunction with Robert Allan Ltd. of British Columbia, where this form of transportation has been operated with great success for several years, are:

Length, o.a.	108·00 m
Length, b.p.	105·00 m
Breadth	24·00 m
Depth	7·00 m
Design draught	5·08 m

Of 530 000 ft^3 loading capacity, the hull is a pontoon with a strengthened deck suitable for very heavy concentrated loads. To aid sea keeping a stabilizing system is fitted and 4-in high deck stanchions are provided to protect deck cargoes. Moving of the vessel will be by tug, hence the interest of the owning company which is well-known for its experience in towing. Functions which have previously demanded manning, such as casting anchor, lighting navigation lights and giving signals will be operated *via* radio from a tug boat: this equipment will be installed by the Svenska A/B Tradlos Telegrafi. The vessel will have three 15-ton Hagglund cranes.



General arrangement 10 000 dwt non-propelled barge

When transporting pulpwood, which the receiver usually stores in the sea, the cargo will be discharged by filling the port tanks of the vessel from the sea, thus heeling the carrier to dump the cargo quickly into the sea; the port side stanchions are portable. Preparations are also being made to make it possible to transport petroleum products underdeck in the tanks of the barge. The loading capacity of the tanks is approximately the same as on deck.—*Motor Ship, April 1969, Vol. 50, p. 4.*

Ship-Lift in Siberia

River vessels on the River Yenisei in Siberia will be taken over the dam of the Krasnoyarsk power station in a self-propelled, gear-wheeled chamber filled with water. Leningrad engineers have designed the project which is described in the newspaper *Sovetskaya Rossia*.

The chamber will travel along inclined toothed rails, which ensures a reliable engagement. A cabin in the front part will enable the operator to control the entire process. The toothed rails will stretch over 1·5 km (1640 yd). The ship-carrying chamber, 90 m (295·25 ft) long, will take two or three "Rocket"-type hydrofoils at a time, still leaving some room for a few motor launches.

The machinery is designed to lift a load of 1500 tons. The chamber is fitted with 148 gear wheels, each having an individual hydraulic drive. A special device will ensure that the chamber is maintained in the horizontal position at any time.—*Shipbuilding and Shipping Record, 24th January 1969, Vol. 113, p. 128.*

World's Biggest Container Ships

The largest, fastest and most powerful container ships in the world are to be ordered within the next few months by Sea-Land Service Inc. ,of Trenton, New Jersey, for expansion of the U.S. company's world-wide services. Designed to Sea-Land specifications by J. J. Henry Inc., the ships will each carry 1128 35-ft containers at a service speed of 30 knots—for which twin-screw machinery totalling 120 000 shp will be required. Because early delivery is essential, the owners have decided to have the ships built in a number of European yards.

Basic particulars are as follows:

Length, o.a.	944 ft 0 in
Breadth, moulded	105 ft 6 in
Depth	64 ft 0 in
Design draught	30 ft 0 in
Deadweight	21 000 tons
Displacement	42 700 tons
No. of containers (35 ft × 8 ft 6 in × 8 ft)	1128
Machinery:	
Steam turbine, twin-screw ...	2 × 60 000 shp
Service speed	30 knots
Maximum cruise speed	33 knots

The new ships will add to the Sea-Land fleet and will not replace any of the existing vessels. In design, they have very fine lines, a prominent bulbous bow, single-skin construction with large box girders under the main deck at each side, a forward deck house for the bridge and some accommodation and the machinery and other accommodation arranged aft of amidships. Two Foster Wheeler D-type boilers will provide steam at 850 lb/in^2 to a pair of twin-cylinder geared steam turbines which exhaust to scoop-inlet, single-pass condensers. Modularized construction is envisaged for the auxiliary machinery systems and for the accommodation arrangements.—*The Motor Ship, February 1969, Vol. 49, p. 531.*

Operating Experience with MWM Medium-speed Engines on Class B Fuel

In 1965 and 1966 the sister ships *Tinnum* and *Archsum* of Messrs Zerssen and Co. of Rendsburg were re-engined with the aim of utilizing the economic advantages of heavy fuel operation. Each of these 4400 hp twin engine single-screw installations consists of two directly-reversible TbRHS 345 AU MWM Diesel engines which are coupled to an f.p. propeller via a twin reduction gear. Built in 1956 and 1958 by the Nobiskrug yard at Rendsburg, they originally had Diesel-electric main propulsion systems, the high-speed engines of which were not suitable for operation on heavy fuel.

Principal particulars are:

Length, b.p.	103·50 m
Breadth, moulded	15·00 m
Depth to upper deck	9·45 m
Depth to 'tweendeck	6·80 m
Cargo capacity, grain	310 506 ft^3
Cargo capacity, bale	280 240 ft^3
Deadweight, closed at 7·7 m draught	6400 tons
Deadweight, open at 6·45 m draught	4820 tons
Service speed	15 knots
Propulsion power	4400 hp

The installation of the new engines was carried out by the Nobiskrug builders, the owners being responsible for the technical planning, especially of the heavy fuel installation. The ships have now been operating on the Hamburg, Rotterdam, Eastern Mediterranean service making two-month round voyages.

The main engines are medium speed eight cylinder trunk-type piston engines of 360 mm bore and 450 mm stroke and an output of 2200 hp at 500 rev/min and for heavy fuel operation, the following changes were made:

1) the light alloy pistons had the normal rings and were provided with oil cooling by means of cast-in coils, but otherwise remained unchanged;
2) the injection nozzles are gas-oil cooled, the oil being taken from the daily service tank by a special cooling oil pump driven by the engine: the heated gas oil flows back to the daily service tank via a cooler: in addition, an electric standby pump is provided for the nozzle cooling which together with an electric preheater can also be used for the warming-up of the injection pumps prior to starting from cold;
3) the exhaust valves have Stellited seats and are provided with Rotocap rotating devices: the valve cages do not have the usual joint at the shoulder in the region of the cylinder head bottom plate, but have a securing flange seated on the upper surface of the cylinder head, and a sliding seal at the lower end: the valve cage can therefore expand freely at its lower end: this arrangement has proved successful, as distortion or deformation of the valve seat due to unilateral sealing forces is impossible: it is a further advantage that the cylinder head bottom plate is kept free of compression stresses arising from pressure of the valve cage: even after long periods of operation, the valve cages can readily be removed: the double seal eliminates oil seepage and hence sticking of the valve cage.

The two engines are coupled to the Lohmann and Stolterfoht Navilus GVA 1250 3·27 to 1 twin-reduction gear by flexible Pneumaflex clutches. The engines and clutches are remotely controlled from a common operating console installed at 'tweendeck level, by means of a pneumatic single lever control system. All the important operating values are indicated at the console and the plant is equipped with the usual safety and interlocking devices.

After 5225 running hours the cylinder liners of *Tinnum* were checked, and showed wear in the upper part of the cylinder liner of less than 0·01 mm per 1000 h. The ring gaps were still within permissible limits. The service life of the Stellited valves equipped with rotators is between 1200 and 1500 h according to the type of service.—*Marine Engineer and Naval Architect, November 1968, Vol. 91, pp. 425–453.*

French-built Tanker for BP

The largest ship yet built by France-Gironde, Dunkirk, *Montsoreau*, is a 125 000 dwt tanker for the Société Maritime des Petroles BP.

The ship has been built for classification by Bureau Veritas ✠ I 3/3L 1/1 A&CP, oil in bulk, No. 2 centre tank reserved for ballast and to satisfy the 1966 loadline convention. One of the features of the ship is the appearance of the prominent bulbous bow, fitted to improve performance in the ballast condition. This bulb is of cylindrical form, having a diameter of 7·5 m, with a hemispherical head. Although incorporated in the original design of the vessel, no attempt has been made to fair the bulb into the ship's lines.

Cargo pumps for this vessel have been supplied through the French subsidiary of Jönköpings Mekaniska Werkstads, Sweden, and comprise two horizontal type pumps, each capable of handling 5000 m^3/h of crude oil, against a head of 125 m. They are driven by two JMW steam turbines each rated at 2700 hp. These are among the largest cargo pumps in use at sea at the present time. In addition to their cargo handling duties, the main cargo pumps can also be used to provide a side thrust of about 11 tons. This is achieved by running a pipe 600 mm in diameter from each of the pumps to a pipe 800 mm in diameter located athwartships. By the use of two remotely controlled valves, the jet thrust from the pumps can be directed to port or starboard as desired. It is claimed that not only will this facility be of use when coming alongside and when manoeuvring in restricted waters but will also be used when going astern as an aid to maintaining the desired course.

Principal particulars are:

Length, o.a.	274·30 m
Length, b.p.	262·00 m
Breadth, moulded	42·00 m
Depth, to main deck	20·30 m
Draught, loaded	14·91 m
Corresponding deadweight ...	124 410 tons (m)
Machinery output	24 000 shp (m) at 91·5 rev/min
Speed on trial at 14·91 m draught	16·35 knots
Block coefficient	0·8456

The propelling machinery comprises a Stal-Laval type AP 28/21 steam turbine which was built, under licence, by Chantiers de L'Atlantique at Saint Nazaire. This engine has a normal continuous output of 24 000 shp (metric) and drives the propeller at 91·5 rev/min.—*Shipping World and Shipbuilder, February 1969, Vol. 162, pp. 318–320.*

Japanese-built Container Ship

Container ship *America Maru*, which is powered by the first 1050 mm bore Sulzer type Diesel engine to be built, has been delivered to Mitsui O.S.K. Lines and is in service between Japan and the Pacific coast of North America. This vessel, of 15 440 dwt, is the third full container ship to be built by Mitsubishi Heavy Industries Ltd., the first two of which were powered by Mitsubishi-built M.A.N. engines.

A flush deck type hull form with engine room and bridge superstructure located in a semi-aft position has been used so as to increase the container carrying capacity. There are four container holds forward of the bridge and one aft. Two longitudinal bulkheads have been installed in a way of the hatch coamings of Nos 2, 3 and 4 container holds and the space between these bulkheads and the shell are used for fuel oil and water ballast tanks. The hull form for this high-speed container ship has been developed from fast cargo-liners *Bergen Maru* and *Barcelona Maru*, both built by Mitsubishi in 1966.

The cell structure, which is one of the noteworthy features of this vessel, represents a successful attempt at rationally reducing the hull weight based on calculations of appropriate strength.

Principal particulars are:

Length, o.a.	610 ft 4⅜ in
Length, b.p.	574 ft 2 in
Breadth, moulded	82 ft 0 in
Depth, moulded	50 ft 10 in
Draught	31 ft 2 in
Displacement	24 400 tons
Deadweight	15 440 tons
Gross tonnage	16 404·77
Service speed, fully loaded ...	22·4 knots
Trials speed, max.	26·38 knots
Cruising range	12 500 sea miles
Complement	33

As the engine room is located well aft where the hull is fine due to hold arrangement needs and as the propelling machinery is a large output Diesel engine, special considerations, such as the reinforcement of the double bottom of the engine room and the additional installation of steel bulkheads in the living quarters, were taken to prevent vibration.

The propelling machinery in *America Maru* consists of a Mitsubishi-Sulzer type 8RND 105 eight-cylinder turbocharged Diesel engine of 1050 mm bore and 1800 mm stroke. This engine is the first large-bore Diesel of Sulzer design to be built under licence. It has a maximum continuous rating of 28 000 bhp at 108 rev/min and a normal service rating of 23 800 bhp at 103 rev/min.—*Shipping World and Shipbuilder, December 1968, Vol. 161, pp. 1902–1904.*

Europe's Largest Oil/Bulk/Ore Carrier

A large oil/bulk/ore carrier of 96 400 dwt has been built at the Arendal shipyard of AB Götaverken, Sweden, for Sigurd Herlofson and Company A/S, Interessentskapet OBO, Oslo. This vessel is the first in a series of three vessels of this type and the largest of her kind yet built in Europe. Named *Obo Prince*, she represents a further development of the series of eight OBO ships of about 75 000 dwt, the construction of which started last year at Arendal.

Principal particulars are:

Length, o.a.	841 ft 5¼ in
Length, b.p.	800 ft 0 in
Breadth, moulded	127 ft 9 in
Depth, moulded	64 ft 7 in
Draught, summer	47 ft 4½ in
Deadweight	96 400 tons
Gross tonnage	52 400·45
Cargo capacity:	
oil	3 974 108 ft^3
grain	3 827 214 ft^3
ore	2 025 564 ft^3
water ballast	907 462 ft^3
Machinery output	19 800 bhp at 115 rev/min
Speed, full draught	15·9 knots

In order to obtain a shorter cargo oil piping system, decreased stresses on the hull and more cargo capacity, the pump room has been arranged amidships between Nos 5 and 6 holds. Above the pump room there is a small deckhouse in which there is a control room for monitoring and handling loading and unloading operations. Equipment has been provided in this space for remote control of the cargo oil pumps and ballast water pump, as well as for the valves in the cargo oil and ballast systems. Remote reading tank level gauges and ship's trim indicators have also been installed.

Three steam turbine-driven vertical cargo pumps, each having a capacity of 3000 tons/h, and one electric motor-driven ballast water pump of 2000 tons/h capacity, are located in the pump room. In order to dispense with separate stripping pumps and piping, a priming system is used for the cargo oil pumps.

The propelling machinery in *Obo Prince* consists of a nine-cylinder, turbocharged, Götaverken Diesel engine of 850 mm bore and a stroke of 1700 mm; developing 19 800 bhp at 115 rev/min and giving the vessel a speed of 15·9 knots at full draught. The propeller has a diameter of 6900 mm and 4700 mm pitch at 0·7 R. The main engine is equipped for operation on fuel having a viscosity of up to 3500 sec Redwood No. 1.—*Shipping World and Shipbuilder, October 1968, Vol. 161, pp. 1622–1624.*

Voith Turbo-coupling for Ship Propulsion

The Voith turbo-coupling is a newly-developed hydraulic coupling for fitting between the engine and the reduction gearing in geared Diesel propulsion installations; it is particularly suitable for highly-supercharged multi-engine installations. A feature of the coupling is that it provides two different relationships between torque and slip, according to whether the coupling has a full charge or a pre-set part-charge of oil; a change-over control is incorporated. In either condition of charge, the coupling can be rapidly emptied and rapidly filled or part-filled again, so that it can be used as a clutch. In the part-charged condition, the slip is higher and remains substantially constant over the whole operating range of rev/min; in this condition it protects the engine from overloading during manoeuvring and permits very slow running. Although the oil remains at the pre-set level there is, in fact, a flow of oil for cooling purposes.

The author describes, in some detail, the construction of the coupling and the principles on which it is based. The first of these couplings were designed for 5100 hp at 475 rev/min, and the rotor diameter was 2200 mm (7·2 ft); the part-charge was pre-set to give 25 per cent slip. Two such couplings were installed in the twin-screw ferry *Nils Holgersson*, which entered service in June 1967.

When the coupling has a full charge, i.e. when not manoeuvring, its efficiency is about the same as that of other types of coupling (about 97–98 per cent). In the part-charged condition the lower efficiency is of minor importance. The cost of the coupling is less than that of some comparable couplings. The Voith coupling can be supplied without the part-charge arrangement, and can then be used as a simple clutch-coupling.—*Bönsch, G., November 1967, Vol. 28, pp. 448–451; Journal of Abstracts of the BSRA, November 1968, Vol. 23, Abstract No. 26 813.*

Improving Trawl Gear and Purse Seine Performance

If the total available thrust of a vessel is known, a suitable board size and net can be designed to match the vessel and several attempts have been made to produce standard formulae for these relationships.

There are so many variables which have to be taken into account that most tables derived from formulae are almost useless.

It is hoped that with the availability of computer systems it will be possible to derive empirical formulae that will be of general use. However, even when detailed information concerning ship's speed, net drags, etc., have been obtained for a particular vessel, there are some simple practical tests, using very limited instrumentation, that can be worthwhile.

For example, the gear research unit at Aberdeen carried out such tests on a 110 hp vessel. The gear previously used on the vessel consisted of a 44 ft headline bottom trawl and the standard 4 ft 'V' type otterboards. Results were consistently poor and, although there was still a reserve of power, increase in speed did not improve matters.

By measuring the total load and the divergence of the warps at the ship, together with the headline height, it was calculated that a 5 ft 'V' board should be introduced. Further measurements were then made. The measurements between the two cases were on average, as follows:

the board spread, calculated from divergence, increased from 40 to 80 ft and the measured corresponding drop in headline height from 6 ft to 3 ft occurred. At the same time, the wing ends were drawn down almost to run on the seabed. A small increase in the tension measured at the ship was noted (about 110 lb). The ship still had an ample reserve of power.

The 5 ft otterboards were then used with an increase in net size. These modifications, using carefully selected otterboard size and a net with an overall 20 per cent increase in drag, were tested and the final spreads and headline heights were approximately midway between the previous results. Catching rates for the new system are much improved over the original.

It is easy to understand why, without these limited measurements and by making single changes to board or net, no improvement in performance was previously achieved.—*World Fishing, February 1969, Vol. 18, pp. 32–33.*

Cargo and Machinery Space Fire Protection Systems

Cargo and machinery spaces in ships are two major fire hazards.

For a considerable number of years, cargo spaces have been provided with either a CO_2 or steam smothering system.

The use of steam smothering is prohibited for passenger ships but is allowed for cargo spaces of ships if certain conditions are met. These cargo spaces do not include those which carry explosives.

The accepted alternative media for cargo spaces are, at the moment, carbon dioxide or inert gas (generated on board). At present there are four accepted media that may be used in machinery spaces:

1) water spray;
2) carbon dioxide;
3) froth;
4) high expansion foam.

Although the present rules permit alternative extinguishing media to be used, up to now it appears that carbon dioxide is the most economic medium when used in systems of traditional design.

The CO_2 is normally stored in high pressure cylinders and the system is entirely independent of all ship's services for its operation. When discharged into a space it is relatively easy to clear and leaves absolutely no evidence of its presence.

There are many experiences of very quick and effective extinction of fires especially in machinery spaces. Fires in some cargos are most difficult to extinguish completely because of smouldering which demands high concentrations of carbon dioxide being maintained, within the space for long periods of time, to enable materials to cool sufficiently to prevent re-ignition.

Government administrations throughout the world prescribe a minimum quantity of CO_2 that must be carried. This minimum quantity must be based on that required for the largest cargo space capable of being sealed or the machinery space, which ever is the larger requirement.

Therefore, in general, dry cargo ships carry a quantity of CO_2 based on the larger of these two risks. If the CO_2 is used to fight a serious machinery space fire there may be none left to deal with a cargo fire and *vice versa*.

This situation can be improved by installing a greater quantity of CO_2 than that required by law.

One well known shipping line has provided their new ships with a quantity of CO_2 which is about four times that prescribed by the Board of Trade. The CO_2 is carried in two low pressure storage tanks and the pressure is carefully controlled by refrigeration to a nominal 0°F. CO_2 filling pipes connect the tanks to convenient on-deck filling stations. The CO_2 storage tanks can, therefore, be filled with CO_2 from road tankers on the dock alongside the ship. The filling operation can be carried out quite simply and by the tanker driver, probably unaided.

Equipment can be fitted which will provide an unlimited fire extinguishing medium. One such system is an inert gas generating plant. The inert gas generator produces an inert gas which is composed of 85 per cent nitrogen, 14 per cent CO_2 and 1 per cent oxygen. The inert gas is produced by burning Diesel fuel oil in a carefully controlled quantity of air.

Such systems produce, typically, between 30 000 and 50 000 ft^3/inert gas/h burning about 25–35 gal/h of Diesel fuel oil. Since ships normally carry large quantities of this fuel and the plant can be run as long as fuel lasts, a very large quantity of inert gas can be available for a cargo fire.

Since such a plentiful quantity of inert gas is available the plant can be started up as soon as the fire alarm is given and the gas can be injected into the space without waiting for the compartment to be closed up. Adjoining spaces can subsequently be inerted against fire outbreak by transfer of heat.

The Board of Trade require an inert gas generator to be capable of producing hourly a volume of free gas at least equal to 25 per cent of the gross volume of the largest cargo space. The quantity of free carbon dioxide that must be available in the conventional system must not less than 30 per cent of the largest cargo space.

It will, therefore, be seen that the inert gas generator after running only 100 minutes will have produced more inert gas than the total CO_2 required by the rules.

A number of ships have fitted inert gas generating systems and they have been used effectively against fires in cargo.

Unfortunately, the inert gas generation rate is insufficient to deal with a machinery space fire. Therefore, in order to afford protection for both cargo and machinery spaces a ship which is fitted with an inert gas generator must have, in addition, another system for the machinery space, say carbon dioxide flooding. This must inevitably be more expensive than the CO_2 system which can be used for both hazards.—*Haines, E. E., Marine Design International, Shipbuilding and Shipping Record, 1969, Vol. 113, pp. 65–67.*

The Current Revolution in Overseas Transportation

The paper discusses the recent change in the philosophy of shipping companies engaged in overseas transportation; emphasis is now laid on the overall movement of cargo from inland point of origin to ultimate destination, rather than merely from pier to pier. An outline is given of some pioneer unitized cargo operations (Seatrain, Sea-Land, Matson Line, Grace Line), of the beginnings of intensive container traffic on the North Atlantic route, and of plans for the Pacific. This is followed by a short review of some of the problems involved in unitization (compatibility with land transport, ship operator's organization, ship and terminal design, documentation). The economic significance of these new developments is then considered, with particular reference to time and cost savings to shippers, the resulting stimulation of world trade to be expected and potential benefits to the economies of both developing and industrial countries. Data are given to show how reductions of a few per cent in overall distribution costs and/or delivery time could make many more U.S. products competitive when exported to Europe or elsewhere.—*Zubaly, R. B. and Lewis, E. V., A.S.M.E. Paper No. 67–TRAN–33, August 28–30 1967; Journal of Abstracts of the BSRA, November 1967, Vol. 23, Abstract No. 26 837.*

Theoretical Analysis of the Thermal and Hydraulic Characteristics of Sea-Water Systems for Low-Speed Diesel Installations

After explaining the basic theory, the author makes a detailed comparison between the characteristics of possible series and parallel sea-water heater-exchanger systems for Burmeister and Wain low-speed Diesel installations of various powers.

Over a wide range of powers, the series layout appears at first sight to be more rational. However, this is only true if a full flow of sea water is fed through the air cooler and if the main pipe is not restricted. Use of the series layout without such restrictions makes the standardization of pumps impossible, since the fresh-water and sea-water systems then require pumps of different characteristics. Thus the parallel system is in fact more rational, because it allows the standardization of pumps. The parallel system must be employed where the engine pistons and cylinders have a common fresh-water cooling system, and can also be used where the engine has separate cooling of pistons and cylinders.

A tabular comparison is made of calculated data for a series system (with and without restriction) and a parallel system for a B. and W. engine of 8750 bhp and of actual data for the system in the motor ship *Bezhitsa* (the performance of which is shown to be far from the optimum).

The analysis should aid the designer in approaching the problem of choosing sea-water system layout, pump output and heat-exchange surface area from the standpoint of minimum pump power, which depends on the method of water distribution in the main and auxiliary machinery, pipe resistance and the intensity of heat transfer in the main heat exchangers.—*Maslov, V. V., Transactions of the Central Scientific Research Institute of the Merchant Marine, U.S.S.R., 1967, Vol. 86, pp. 11–23; Journal of Abstracts of the British Research Association, December 1968, Vol. 23, Abstract No. 26 918.*

Titanium Plates for Heat Exchangers

After a considerable period of research and testing, the Alfa-Laval Co. has introduced titanium plates in their plate-type heat exchangers which are now used extensively in all classes of ship and which have hitherto been offered only aluminium-brass plates. However, in some areas such as the Baltic Sea, the Danish Sound and the English Channel, the waters are substantially more corrosive than elsewhere. Certain rivers, like the Thames, are also highly corrosive because of chemical and sewage deposits. Consequently ships sailing regularly in these waters, whether with conventional tube-type or plate-type heat exchangers, have encountered considerable corrosion damage to their cold water systems, including the coolers, with serious effect on maintenance costs.

The effectiveness of titanium in resisting corrosion was shown in the decision of Townsend Car Ferries Ltd. to try out the new titanium plates in the Alfa-Laval heat exchangers on their car and passenger ferry *Free Enterprise III*. The ferries operated by this company are in service between Dover, Calais and Zeebrugge, where the harbour waters are heavily polluted.

Since 1966 the titanium plate-type coolers in *Free Enterprise III* have given continuous trouble-free service: sufficiently satisfactory for the owners to install their newly delivered triple-screw *Free Enterprise IV* four separate banks of P252 titanium plate-type coolers by Alfa-Laval Co. for both jacket water and oil cooling of the three 4080 bhp Diesels.—*The Motor Ship, April 1969, Vol. 50, p. 36.*

Vibration Isolation of Elastically-Mounted Marine Engines

As the usual type of marine-engine foundation is a framework, its mechanical impedance is less than that of the massive engine-foundations common in land practice; the two types of foundation therefore react differently to engine noise and vibration, and the difference is significant at frequencies above 100 c/s. A consequence of this is that the equations generally used in calculating the vibrations and noise-isolating effects of elastic engine-mountings are of only limited validity when applied to elastic mountings for marine engines.

The author discusses the problem of establishing the value of the effective mechanical impedance, for use in marine engine-mounting calculations. Equations are derived for the approximate calculation of the effectiveness of the structure-borne noise isolation of ships' elastic mountings. Added masses fitted below the resilient elements are suggested as a method of increasing impedance and improving vibration-isolation. Data are given on the reduction in structure-borne noise to be expected from this method. The double-isolation method is also mentioned.—*Hahold, S., M.T.Z., November 1967, Vol. 28, pp. 464–469; Journal of Abstracts of the BSRA, November 1968, Vol. 23, Abstract No. 26 832.*

Planet Gears Used in East German Deck Equipment

Planetary gears are now being used in the drives for windlasses and hauling capstans on several deep-sea vessels at present under construction and recently completed in East Germany. This arrangement, developed by VEB Getriebewerk Gotha, is said to be lighter and more compact than the more usual worm gears. Shipyards in East Germany are now using only capstans fitted with planetary gears, usually in conjunction with an a.c. change-pole type of motor.

The gears, which are manufactured in nine sizes with capacities up to 52·6 hp for windlasses and seven sizes up to 34 hp for hauling capstans, have been extensively used in stern strawlers of the *Atlantic* type and in the "10D"-type semi-automatic cargo ships.—*The Motor Ship, April 1969, Vol. 50, p. 54.*

Indirect Drive: A Coupling Proposal

The direct drive Diesel engine has developed enormously in size and power in recent years, to the extent of 4000 bhp per cylinder in the speed range 105/115 rev/min with very low specific fuel cost; such that it gives intense competition to the marine turbine classes of vessel wherein steam power has up to the present been dominant.

Another striking development in the Diesel engine field is the medium-speed engine, with an output ranging from 500 to 1000 bhp per cylinder, in the speed range 400–500 rev/min, that is convenient for a geared drive to the propeller. Such engines are most compactly arranged as twin units, hence with a combined output of 12 000 to 24 000 bhp in 12-cylinder versions.

If Diesel machinery is acceptable for a specific class of vessel and service within the above power range, a good technical and commercial case is now present for having two medium-speed direct-reversing engines, geared to drive a fixed-pitch screw at a suitably low speed to achieve good propeller efficiency.

Consideration will properly be given to the alternative selection of twin uni-directional engines, geared to drive a controllable-pitch propeller, with the facility for constant speed operation for driving an auxiliary generator from a main engine. In such an installation, a torsionally-flexible coupling, of which several types are available, would be mounted on the engine crankshaft to smooth out the vibrations in the geared drive.

Reverting to the direct-reversing geared engine, an hydraulic coupling or magnetic slip coupling could well be selected for the connexion/disconnexion with the respective pinion shaft. Such couplings have inherently good torsional vibration-smoothing characteristics, and also provide the facility, when such is required, for control of the slip to give specially low propeller speeds. On the other hand, the minimum slip loss and consequent increase in fuel consumption constitutes a deterrent, when the extra cost is considered over the life of the vessel.

A pneumatically-operated friction clutch, in combination with a torsionally-flexible coupling, might well be chosen because of the compact size, as well as low capital cost and the absence of continuous slip loss; although subject to some limitations of capacity, hence calling for good engineering judgment in relation to the higher power engines.

There is, however, another good solution, namely, to use a direct-reversing geared engine with a hydraulic coupling of simple construction, incorporating a synchronous-engagement toothed clutch, to give slip-free direct drive during sustained periods of ahead propulsion. The clutch would, of course, be disengaged to transfer the drive to the full hydraulic coupling prior to the execution of a crash astern order, and likewise prior to the commencement of manoeuvring operations, to take advantage of the soft drive through the full hydraulic coupling.

The inherent torque/slip characteristics of such a coupling are valuable, in so far as they permit the engine to be stopped and reversed readily, and its power applied to stop and reverse the propeller rotation while the vessel continues in motion. This is achieved without any possibility of inadvertent stalling of the engine during the manoeuvre. A torsionally-flexible coupling of suitable characteristics would be mounted on the engine crankshaft, to smooth out vibrations during the normal direct drive condition with the toothed clutch in engagement.

The multiple tooth clutch in question would be of simple construction, ulitizing the lubricating oil pressure supply for hydraulic servo actuation, and its control would be effected in a simple manner.—*Sinclair, H., Marine Engineer and Naval Architect, March 1969, Vol. 92, pp. 107–109.*

Twin-screw Sewage Sludge Carrier

Built by Ailsa Shipbuilding Co. Ltd. of Troon for the City and County of Bristol, a 900 dwt twin-screw sewage sludge carrier, has a computer and a comprehensive outfit of alarms and automatic controls which enable her to be operated without any engineering staff. Provision has been made in the initial design for lengthening, to match the growing population of Bristol. Machinery consists of two Ruston radiator-cooled AP3 engines driving fixed pitch propellers through MWD reverse-reduction gears.

Vessels intended for this duty generally have high double bottom void spaces below the cargo tanks to ensure that complete discharge can be effected by gravity. This construction with its inevitably high freeboard and large windage area in the light ship condition could not be adopted in this case due to the exposed location of the dumping area in the open Bristol Channel and the problems of navigating the narrow and winding river Avon. It has, therefore, been arranged that the cargo is discharged by a combination of gravity and low pressure air applied to the tanks. This can be effected in 15 minutes.

There are four cargo tanks, two on each side. The two forward tanks are of about 236 tons capacity and the two after tanks of about 230 tons capacity (sewage sludge is about 1·035ft^3/ton) and provision has been made in the design for lengthening the ship by the addition of one more tank, raising the deadweight by 30 per cent. The dump valves are of cylindrical type and are operated by Limitorque electric actuators powered by 0·55 hp electric motors. Each tank has two cylindrical hatches with a patented closure. Tests had shown that towards the end of the discharge, there was a tendentcy for a "bath-plug" vortex to develop, with loss of air pressure. Anti-swirl devices designed by Strathclyde University have therefore been fitted in the vicinity of these dump valves.

Control of the entire machinery installation is performed by an English Electric automatic watchkeeping installation. All the essential auxiliaries are duplicated and protection against serious failure is provided for by automatic engine shut-down controls (with manual override where navigation considerations must prevail) together with standby engine service pumps, automatic bilge pumps and automatic generator change-over. This comprehensive automation and remote control system permits the operation of the machinery with the engine room unmanned, indeed without any engineering staff on board. This results in the saving of five crew members with attendant benefits in terms of a reduced wage bill, the need to provide accommodation, victualling, etc.

A small and relatively unsophisticated computer capable of analysing and comparing related parameters, and indicating normal or deteriorating performances is the heart of this watch-keeping system. English Electric have used an M2110 machine from the System M range of industrial automation equipment for their first application of a computer at sea. The use of a stored programme computer facilitates a standard approach to a wide variety of marine watchkeeping systems, while providing a flexibility and sophistication unobtainable from wired logic systems of comparable cost. The M2110 contains the necessary electronic logic to perform analysis and computational work on data which is gathered during the scan of analogue and digital points located in the plant. Instructions which define the data processing routines and any other information required by the processor—such as constants, scaling factors and message outputs—are retained in the core store, or memory, which is capable of storing 4000 words of data. The computer presents data to the engineer in the form of print-out on one of the system Teletype machines, or as digital displays on the watchkeeping system control panel, or as flashing alarm indications on remote alarm and machinery panels.

Information is obtained by the automatic watchkeeping system from the ship's machinery by analogue signal (temperatures, pressures and levels) or state signals provided by contact closures on machinery. Some 100 analogue signals furnish a trend record of gradual changes in machinery performance, while 197 state inputs provide a record of any sudden changes, such as a machine shutting-down, a standby machine starting-up or a sudden overload condition arising. Signals are fed into the processor via an analogue or digital scanner unit, as appropriate. The points monitored by the analogue scanner embrace the main engines, gear-boxes, engine services, air compressors, stern gland oil systems, auxiliary generators and major cargo tanks.

The connexion between bridge control equipment and engines in the unmanned engine room is pneumatic. Since the main engine speed and direction controls are already mounted in the ship's console, together with the engine running lights and provision for overriding a main engine shutdown, proper control of main engines is exercised by centralizing all the necessary controls and indicators on the ship's control console. Associated with the main engine start/stop control are a number of lamps to indicate the state of each engine. These lamps provide early warning at the bridge control position of any faults which may be developing and enable the helmsman to act quickly in case of emergency and, if necessary, to override imminent automatic shut-down. —*Marine Engineer and Naval Architect, March 1969, Vol. 92, pp. 100–106.*

New Brazilian Shipbuilding Programme

A two-part shipbuilding programme, authorized by the Brazilian Government, consists of 24 fast cargo liners of 12 000 dwt each and of 11 cargo vessels of 7600 dwt each, the constructions being financed by the Brazilian Merchant Marine Commission.

The cargo liners will be highly automated and three-quarters-aft type vessels with long poop and forecastle, three decks and five holds. The hull form is designed in view of the high speed and incorporates a modern bulbous bow and clear water type stern configuration. Deep tanks having a capacity of about 1000/m^3 will be fitted forward in No. 1 hold. They will be suitable to carry vegetable oils, general cargo or water ballast. The aftermost hold, No. 5, will be refrigerated. The other hold and tweendeck spaces will be fitted for general cargo, holds Nos 2, 3 and 4 also for standard 20 ft containers. All these holds will be fitted with Cargocaire equipment. The total capacity will be 19 822/m^3 grain and 18 403/m^3 bale. A combination of deck cranes and derricks are provided for easy and quick cargo handling. Nos 3 and 4 holds will be triple hatches abreast with centreline hatches elsewhere. The hatches will have MacGregor Single Pull hatch covers on the weather decks and MacGregor/Ermans Flush Sliding hatch covers in the tweendecks. On these ships the hatch cover surfaces will be about 33 000/m^2.

The cargo vessels are designed for the carriage of containers and for general cargo. Operator will be Linhas Brasileiras de Navegacao S.A. and the construction will be carried out by: Industrias Reunidas Caneco S.A. (four ships), Estaleiros So S.A. (two ships), and Engenharia E.Maquina S.A. (five ships). The delivery is scheduled to begin at the end of 1969.

These vessels are equipped with three holds with Mac-

Gregor Single Pull hatch covers on the weather deck and also MacGregor/Ermans Flush Sliding hatch covers in the tween deck. The covers will protect an area of about 6500/m^2 and will be designed to withstand one layer of 20-ft standard containers.—*Hansa, 1969, Vol. 106, No. 4, p. A34.*

LPG Carrier for Norwegian Owners

The vessel described in this article is the liquefied petroleum gas carrier *Kristian Birkeland*, built by Chantiers Navals de La Ciotat, France, for Fearnley and Eger, Norsk Hydro and Gazocean Norsk, Oslo. This new vessel, which has a capacity of 785 596, is one of seven L.P.G. carriers ordered from the La Ciotat shipyard.

Principal particulars are:

Length, o.a.	561 ft 0 in
Length, b.p.	521 ft 7$\frac{7}{8}$ in
Breadth, moulded	80 ft 0$\frac{5}{8}$ in
Depth, moulded to main deck ...	50 ft 10$\frac{1}{4}$ in
Draught, summer	28 ft 8$\frac{7}{8}$ in
Displacement, corresponding ...	24 852 tons
Gross tonnage	16 532·42
Light ship	8326 tons at 10 ft 7 in
Machinery output	13 800/m hp at 122 rev/min
Speed, trials	17 knots

Kristian Birkeland has been built under the supervision of Det Norske Veritas to classification ✠ 1A IFR "ISC" "EO" (Liquefied gas carriage at −48°C and 0·275 bar). She has been designed for the carriage, at atmospheric pressure, of ammonia at −33°C, propylene at −47·7°C, butadiene at −4·4°C propane at −45°C and butane at −5°C. Cargo is carried in three holds having a total capacity of 785 596 ft^3.

For drying the air in the cargo tanks (initial conditions temperature 30°C and humidity 70 per cent: final dewpoint condition −15°C), there are two air cooler batteries, operating in series, fed by the refrigeration plant, with one steam heater and one electric motor-driven blower. Air in the tanks is dried only after the tanks have been completely cleared three times.

The propelling machinery in *Kristian Birkeland* consists of a six-cylinder two-stroke Fiat Diesel engine type 906 S. This engine has a bore of 900 mm and 1600 mm piston stroke. The maximum continuous output is 13 800 m hp at 122 rev/min. A four-bladed Cunial propeller of 5900 mm diameter is fitted.—*Shipping World and Shipbuilder, October 1968, Vol. 161, pp. 1641, 1642; 1645–1648.*

Norwegian-built Refrigerated Vessel

The latest ship to join the fleet of the Maritime Fruit Carriers Co. Ltd. of Haifa, Israel, *Persimmoncore*, was built by A/S Akers Mek. Verksted, Oslo.

This open/closed shelterdeck vessel with machinery and accommodation all aft of amidships has four holds, No. 4 being aft of the bridge superstructure.

Principal particulars are:

Length, o.a.	485 ft 0$\frac{1}{8}$ in
Length, b.p.	445 ft 4$\frac{1}{2}$ in
Breadth, moulded	65 ft 7$\frac{1}{2}$ in
Depth, moulded to upper deck ...	41 ft 0 in
Depth, moulded to second deck	31 ft 10$\frac{5}{8}$ in
Draught, summer (open)... ...	28 ft 0 in
Draught, summer (closed) ...	30 ft 0$\frac{3}{4}$ in
Deadweight (open)	8420 tons
Deadweight (closed)	9710 tons
Gross tonnage	5927 tons
Cargo hold capacity	401 388 ft^3
Machinery output ...	10 500 bhp at 115 rev/min
Trial speed	21·24 knots

Propelling machinery comprises a seven-cylinder two-stroke turbocharged Akers B. and W. Diesel engine of the DM-774-VT2BF-160 type developing 10 500 bhp at 115 rev/min n.c.r. and 11 500 bhp at 119 rev/min at m.c.r.

This ship's data logger is of Brown Boveri make, having individual alarm lights set in a mimic panel with separate sections for boilers, main engine, tanks, auxiliaries and refrigeration equipment. On the left of the console, is an IBM teleprinter which logs hold temperatures and brine supply details. Two scanning speeds can be selected for registering data at two or five points per second. Hold temperatures can be automatically maintained at pre-set values.

An improved system of engineers' alarm warning is fitted. This equipment can be switched to give an alarm in the cabin of the engineer on watch as well as giving visual and audible alarms in the engine room, officers' mess, bridge, tunnel and engineers' alleyway. Three different sounds are used depending on the severity of the fault, siren, horn and buzzer.—*Shipping World and Shipbuilder, November 1968, Vol. 161, pp. 1776–1777.*

Disc Brake for Gas Turbine Installation

A twin-caliper disc brake, designed and manufactured by the aviation division of the Dunlop Co. Ltd. (Engineering Group) at Coventry, has been fitted to H.M.S. *Exmouth*, the first major warship in the West Navies to be completely propelled by gas turbine engines. The brake comprises two cast iron calipers operating on a 22-in diameter chrome-plated copper disc. A total of eight pistons apply the load pneumatically at over 1000 lb/in^2 on to the same number of friction pad assemblies, thus bringing the idling propeller shaft, gear-box and compressor section of the turbine engine to rest in 12 seconds.

Continued application of the brake holds this machinery stationary against the idling power of the engines. The brake lever is linked with the engine controls so that release of the brake and application of engine power are achieved simultaneously. This combined with selection of any degree of forward or astern thrust from the controllable-pitch propeller, results in a high degree of manoeuvrability.

The brake itself is situated on an extension of a gearbox pinion shaft and is readily accessible for routine inspection or friction pad changes, which can be carried out *in situ*.—*Motor Ship, April 1969, Vol. 50, p. 53.*

Fractographical Examination of Lamellar Tearing in Multirun Fillet Welds

One inch thick test plates of BS 15 mild steel for general structural purposes have been joined by multirun fillet welds to produce lamellar tearing in the heat-affected zone. Fractographical samples were taken from these lamellar tears and similar fractures in the parent material. Examination of these samples has shown the association of inclusions with the fracture path and has resulted in the proposal of a micromechanism to describe lamellar tearing.—*Elliott, D. N., Metal Construction and British Welding Jnl, February 1969, Vol. 1, No. 2s pp. 50–57.*

Proposal for the Testing of Weld Metal from the Viewpoint of Brittle Fracture Initiation

A method of testing weld metal for its sensitivity to brittle crack initiation is described. The method is based upon consideration derived from the present stage of experience and on considerations of feasibility by industrial laboratories. Interested parties are invited to carry out tests on the basis of the proposal, in order to investigate the practicability of the test and eventually to contribute to a collection of data necessary to improve testing requirements.—*van den Blink, W. P. and Nibbering, J. J. W., Metal Construction and British Welding Jnl, January 1969, Vol. 1, pp. 35–43.*

Development of a Superlarge Bore Engine

This paper deals with the development of the new large Diesel engine type K98FF. The results from service, concerning the fouling of the hull between dockings, show a decrease in propeller revolutions of two to three per cent for constant torque, and this means that the owner can obtain the best utilization of the engine power during the periods between dockings by dimensioning the propeller for 102 to 103 per cent of the nominal revolutions. The paper also describes new design features of the K98FF engine.—*Andersen, C., presented at a meeting of the North-East Coast Institution of Engineers and Shipbuilders, 17th March 1969.*

Notch Brittleness After Prestraining

Notched plates and bars prestrained in compression or extension, before or after notching, at 70°F or 550°F were tested to fracture in tension at −16°F. It was found that a catastrophic reduction of ductility could be caused by small prestrains. Uniform longitudinal or transverse prestraining by as little as 0·05 at 70°F reduced the initial ductility of notched bars by a factor of four or more. Hot prestraining was even more damaging.—*Mylonas, C. and Kobayashi, S., Ship Structure Committee, Report SSC-192, January 1969.*

Arc Welding in the Ocean

Underwater metal arc welding has, since the first serious experiments during World War II, been surrounded with a multitude of problems, as one might expect when introducing flame and heat into water. It seems that most engineers are convinced that the operation of underwater welding is, at best, a very temporary method of repair. Nevertheless, the author has proved in practical fashion to the contrary, that underwater welding can be highly successful even in the most hazardous conditions in deep water with a rough sea.—*Elliss, J. B., Metal Construction and British Welding Journal, March 1969, Vol. 1, pp. 151–153.*

Building Mammoth Tankers in Two Halves

Building large seagoing ships in two halves, with joining done afloat, is a new technique. Nederlandsche Dok en Scheepsbouw Maatschappij (NDSM) claim to be the first to adopt this method when building the 210 000 dwt tanker *Melania*. This article explains why the method was adopted and the special techniques which were needed to make it a success.—*Herfst, L. P., Metal Construction and British Welding Journal, March 1969, Vol. 1, pp. 121–125.*

Bending Moment Distribution in a Mariner Cargo Ship Model in Regular and Irregular Waves of Extreme Steepness

A 1/96-scale model was cut to form six segments, which were joined by a flexure beam. The beam was strain-gauged to measure bending moments at the hull cuts at stations 5, 7½, 10, 12½ and 15. The model was tested with normal weight distribution and with an extreme "cargo amidship" loading in both head and following seas. The range of regular-wave steepness (height/length) was 0·05 to 0·11; the irregular waves had an equivalent full-size significant height of 39 ft.—*Maniar, N. and Numata, E., Ship Structure Committee, Report SSC-190, November 1968.*

Finite Difference Solution for Longitudinal Strength

The conclusions reached by the authors are that the finite difference method is a satisfactory way of solving the longitudinal strength calculation. The finite difference method is quicker than the existing methods. A smaller computer can be used with the finite difference method. The weight curve of a ship can be considerably simplified, thus saving time and expense in the design office.—*Ross, C. T. F. and Assheton, P. R., Shipping World and Shipbuilder, March 1969, Vol. 162, pp. 453–454.*

Data-Logging Equipment for use on board Tankers

Special importance is nowadays being attached to rationalization and, as a result, automation, in the shipping industry. Thus, a large proportion of the important and continuously monitored engine room variables are no longer indicated by conventional analogue methods, but are logged by a central data logging system. This article, condensed from *Siemens Review*, describes such a system, developed in Germany by Siemens AG and fitted into six oil tankers.—*Brandenburg, K., Automation, February 1969, Vol. 4, pp. 16–18.*

On the Vibrations of Horizontal Shafts Supported in Oil Lubricated Journal Bearings

Based on a pressure solution for an infinitely long journal bearing, the vibrations of a rotating shaft which is supported in oil lubricated journal bearings is investigated both theoretically and experimentally.—*Ono, K. and Tamura, A, Bulletin of the Japan Society of Mechanical Engineers, 1968, Vol. 11, No. 47, pp. 813–824.*

The National Engineering Laboratories and Their Role in Fostering Industrial Innovation

This paper discusses briefly all the Government engineering research establishments as well as the money and manpower involved. It then takes the National Engineering Laboratory as an example and outlines its development, its changing directives and organization for control, its present facilities and main fields of activity.—*Paper by Penny, F. D., presented at a meeting of The Institution of Engineers and Shipbuilders in Scotland, 28th March 1969.*

Combustion of Heavy Fuel Oil in Gas Turbine Exhaust Gas

The purpose of this paper is to discuss the combustion of heavy fuel oil in gas turbine exhaust gas. Presuming that existing problems lie in the stability of flame and the absorption of radiant heat in the furnace, the authors have undertaken an experiment, using a test furnace. They found that the stability of the flame worsened and radiation from the flame became smaller as the oxygen content in the combustion air decreased. Similar phenomena were observed when combustion gas was recirculated to the burner.—*Koyama, S., Saito, Y., Nakahara, T. and Ueya, K., Mitsubishi Technical Review, 1969, Vol. 6, No. 1, pp. 62–71.*

Some Variables in Lamellar Tearing

Lamellar tearing generally arises because of the inability of certain steels to accommodate strains applied in the thickness direction during the welding process. While the strain distribution caused by the welding is indeterminate, the temperature cycle can be examined. Tests were carried out to assess the probable effect of temperature changes during welding on resistance to lamellar tearing. There was ultrasonic evidence that lamellar tearing did take place immediately after welding.—*Jubb, J. E. M. and Hammond, J., Metal Construction and British Welding Jnl, February 1969, Vol. 1, No. 2s, pp. 58–63.*

A New Approach to Numerical Control for Shipbuilding

In the author's opinion the next phase of development in shipbuilding should be the employment of digital systems, based on computer, for design and production processes. A flexible processing system is required for integrating a number of numerical control activities and this is ensured by developing the computer programmes on a modular basis.—*Chadbund, J. E. and Parker M. N., presented at a meeting of The Royal Institution of Naval Architects, 26th March 1969.*

A Strain Gauge Torsionmeter for Ship Shaft Systems

In 1957, the Ship Division of the National Physical Laboratory started upon a research programme using a torsionometer to measure torque on small diameter (four-inch) shafts. Because of the small diameter involved, together with the general strain gauge experience of the division, it was decided to use a strain gauge system. Since that date a number of shaft systems have been gauged. Critical examination of the results has led the author to believe that a strain gauge torsionmeter is as good as any system for all practical applications.—*Boyle, H. B., National Physical Laboratory, February 1969, Ship Division Ship Report No. 126.*

Evaluation of Mechanical Properties of Hydraulic Oils

Eighteen experimental formulations, using different antiwear additives, have been studied. They have been evaluated in the Vickers V-104 C vane pump test, in the four ball Extreme Pressure and Wear tests and in the Timken test. Under the conditions of the present study, no correlation has been observed between the outcome of the Vickers test and results of the other mechanical tests.—*Renard, R. and Dalibert, A., Journal of the Institute of Petroleum, March 1969, Vol. 55, pp. 110–116.*

Patent Specifications

Ships Steering Gear

As shown in Fig. 2, the hull of a ship has in its forepart been furnished with a steering gear according to the invention, comprising a propeller 3, arranged in a tunnel 5 located transversely in relation to the longitudinal axis of the ship and with apertures 7 and 9 in the sides of the hull, and screens 11. At the aft edge of the tunnel aperture 7 a screen 11 is shown arranged in a plane mainly transverse to the longitudinal axis of the ship. When the propeller 3 is driven to pump water through the tunnel 5 towards starboard, the torque K1 induces a yaw to port. When the ship is running ahead, the screen 11 will, due to the resistance of the water against it, be influenced by a force K6 which, through its moment arm A, brings about a yawing moment to port. Just behind a screen 11 the pressure in the water decreases, causing a thrust K7 off the port side of the forepart of the ship, which force also brings about a yawing moment to port. The fore-part of the ship is also influenced by the forces K2, K4 and K5, counteracting the yaw.

While the ship is running ahead, the screen 11 improves the flow of water to the tunnel 5, and the torque K1 increases. By its resistance to the water the screen 11 brings about a force K6 which gives a yawing moment. By decreasing the pressure in the water along the ship side just behind the screen, the screen brings about a force K7 which results in a yawing moment.

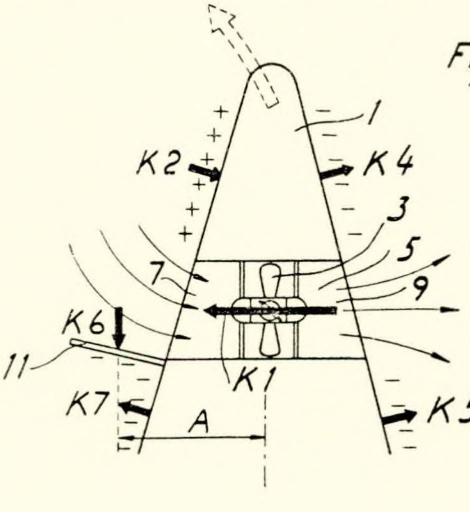


Fig. 2

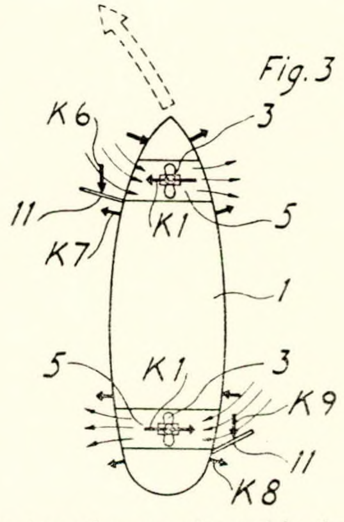


Fig. 3

Fig. 3 shows a ship provided with two steering gears according to the invention, one located in the fore-part and one in the aft part of the ship. When the ship runs ahead, during a yaw to port, the steering gear in the fore-part works as described in connexion with Fig. 2. The starboard screen 11 of the steering gear in the aft part of the ship, is pushed out and produces yawing moments, caused by the torque K1 from the propeller 3 and a force K8 behind the screen 11 to act upon the hull. The screen 11 will, however, be exposed to a force K9 which by its direction in relation to the yawing centre of the ship will counteract the yaw.—*British Patent No. 1 146 915 issued to Aktiebolaget Karlstads Mekaniska Werkstad. Complete specification published March 26th 1969.*

Device for Loading and Unloading a Tanker

Referring to Figs 1 and 2 a hull 10 is illustrated; the central perpendicular 12 of the hull has a specific list in relation to the vertical 13. The centre of gravity of the hull is designated by numeral 14 and the centre of gravity of the liquid displaced by the hull is designated by numeral 15. The torque produced by the buoyancy is shown by the arrow 16. The oblique loading of the hull produces the rolling moment 17.

When the predetermined angle of list is reached, both torques are equal. According to the invention, this state is to be stabilized by a regulating programme. If the stabiliza-

Fig. 1

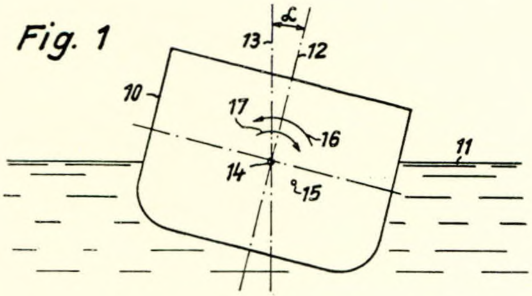


Fig. 2

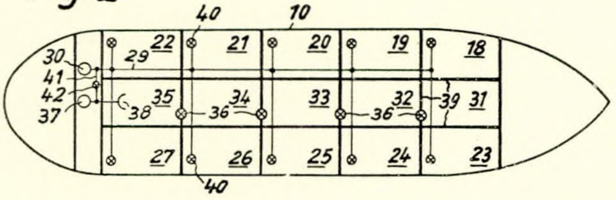
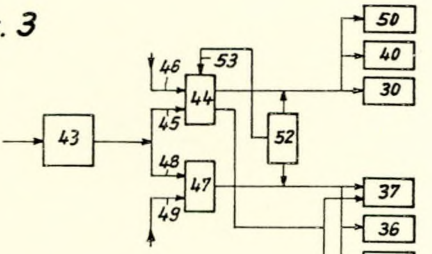


Fig. 3



tion were to be effected about the vertical 13, with the inevitable small overshooting, the sign of the rolling moment would change correspondingly often which might cause oscillations dangerous for the stability of the ship. The predetermined angle of list is so great that the change of sign in the rolling moment cannot appear during the overshooting of the control.

The tank hold in the hull 10 (Fig. 2) is divided into a number of individual sections. The individual sections 18 to 22 are at the port side and the individual sections 23 to 27 are connected to one another by a pipeline system 29 having a remote-controlled intake valve 40 for each section and are connected to a first main pump unit 30. The individual sections 31 to 35 are situated amidships and can be connected to one another by means of remote-controlled valves 36. A second main pump unit 37 draws the cargo present in the individual sections 31 to 35 through the intake 38. The section 35 is first pumped out while the valves 36 remain closed. The valves 36 are then opened and the sections 31 to 35 communicate with each other and can be pumped out while remaining in communication. After pumping out the section 35 and opening the valves 36 cargo flows out of the front individual sections 31, 32, 33 and 34 respectively, so that the ships becomes lighter forward. A system of bulkheads 39 serves to divide the total tank hold into the individual sections described. The intake valves 40 provided in the individual sections 18 to 27 are arranged as close as possible to the bulkhead 39 at the stern side of their particular individual section in order that the minimum level necessary for the operation of the main pumps may be retained for as long as possible.

Fig. 3 shows a block circuit diagram for the device covered by the specification. The basic sequence programme for loading or unloading all the individual sections is fed into block 43. The list-control which covers the sections 18 to 27 at the outside of the hull is effected in block 44 from which the main pumps 30 and the valves of the intakes 40 are actuated.—*British Patent No. 1 146 698 issued to Licentia Patent-Verwaltungs G.m.b.H. Complete specification published March 26th 1969.*

Method of Loading or Unloading a Fluid into or from a Ship

This invention relates to a method of loading or unloading a fluid into or from a tank ship secured to at least one buoy floating in the water. Fig. 1 shows a side-view of the line and the buoy plus appurtenance in the rear position. Fig. 2 shows a rear view of a tanker occupied in loading or unloading.

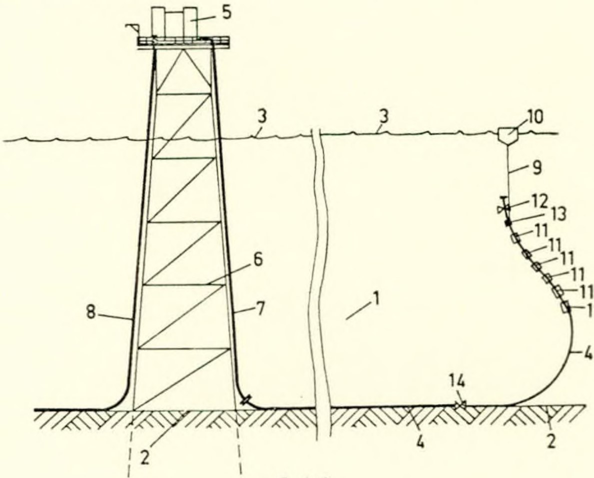


FIG.1

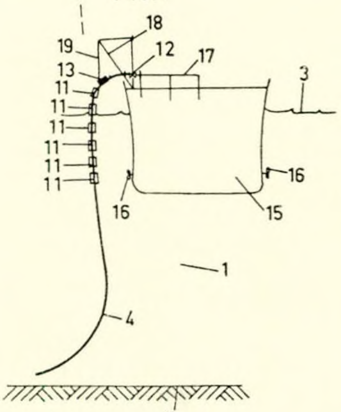


FIG.2

The drawings show the sea 1 having a bed 2 and a surface 3. A line 4 for the supply or offtake of the fluid to be loaded or unloaded lies on the sea bed 2. The line 4 is connected via a line 7 to a separator 5 which is arranged on a steel or concrete structure 6.

In the separator 5, for example, water is separated from petroleum produced from the bed 2, or in the separator 5 water or condensed hydrocarbons are separated from natural gas produced from the bed 2. The oil or gas produced is passed to the separator 5 via a line 8. A ship 15, for example a tanker, is shown in Fig. 2.

The ship 15 is provided with means for automatically positioning it without the use of anchors. These means comprise a system consisting of the extra propellers 16 and an appurtenant automatic control device for operating the extra propellers 16 in such a way that the ship 15 is held in the desired position without the use of anchors.—*British Patent No. 1 144 977 issued to Shell Internationale Research Maatschappij N.V. Complete specification published March 12th 1969.*