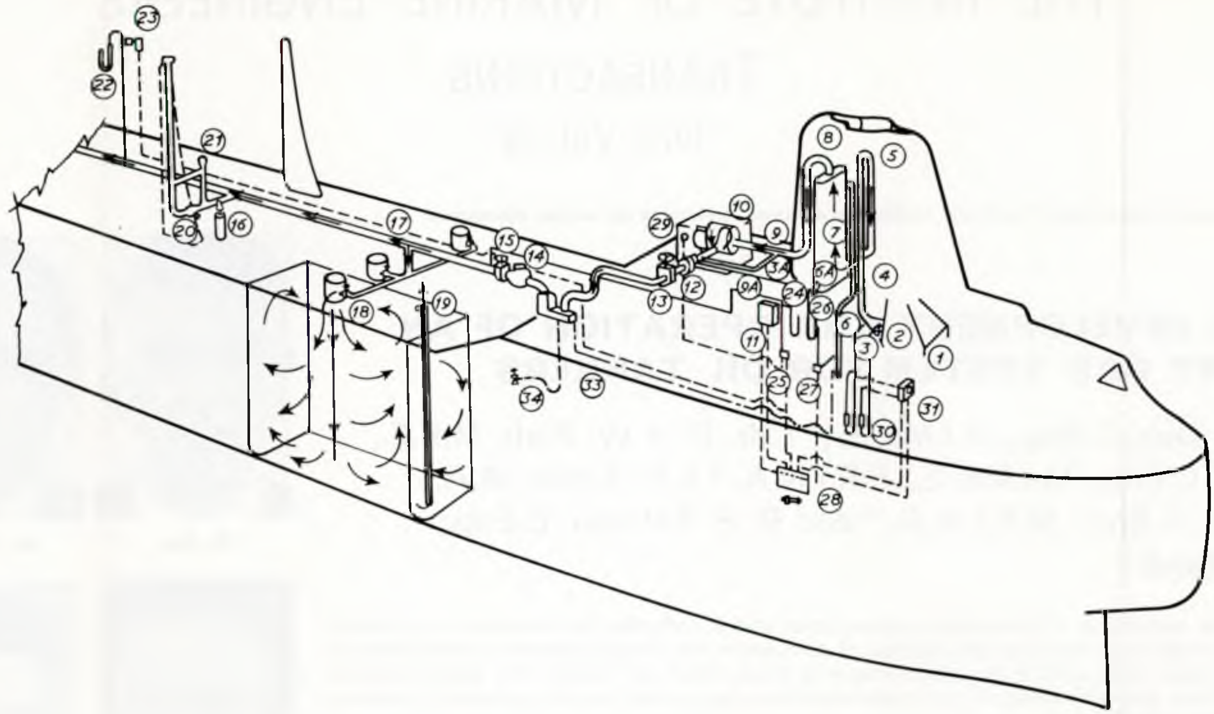


FIG. 1—*Prototype inert gas system*

1 Furnace uptake
2 Flue gas offtakes (one from each boiler) controlled by butterfly valves
3 Blank flange to be opened if it is necessary to ventilate system with air
3a Alternative position of blank flange in some ships
4 Flue gas riser
5 Top loop of flue gas riser (above upper level of scrubbing tower) dropping to gas inlet at foot of scrubber.
6 Water supply to top of scrubber
6a Water offtake from foot of scrubber (piped overside)
7 Scrubbing tower
8 Washed cooled gas offtake from the top of scrubber
9 Main 14 in gas supply along fiddley top to blower
9a Bypass line returning to tower (operative when 12, 13, 14 or 15 are shut)
10 Blower and motor in hut
11 Blower motor control in engine room
12 Servo valve shut down on failure in 6, operated by pressure stat 27
13 Isolation stop valve on main inert gas line
14 Balanced one-way valve permitting inert gas to flow forward only
15 Main inert gas stop valve
16 Oil seal pressure release safety device
17 14 in main inert gas header
18 Branch distribution gas valve (after port wing tank)
19 Purge pipe (inert gas and air)
20 Gate valve on vapour line at foot of vertical riser on samson post (or masts), kept shut when inert gas system operative and open during loading and ballasting
21 P/V valve on bypass pipe around gate valve 20 set to release at 2 lb/in^2
22 Bridge manometer
23 Bridge low pressure alarm and warning light, linked to low gas pressure alarm (No 3 on panel) in engine room
24 Engine room manometer registering pressure in main header by main inert gas stop valve, 15, and linked to low pressure alarm
25 Pressure stat between engine room manometer, 24, and engine room alarm panel, 28
26 Second engine room manometer registering pressure delivered by blower just before servo valve, 12
27 Pressure stat in water supply line to scrubber, linked to low water pressure alarm (No 6 on panel in engine room) and to automatic switch, 29, in blower cabin which actuates servo valve, 12
28 Engine room warning light panel with klaxon linked to low gas pressure alarms on bridge and in engine room
29 Automatic switch controlling compressed air operated servo valve, 12
30 Aspirators for Cambridge CO_2 recorder accepting samples from each boiler
31 Cambridge CO_2 recorder indicating level of CO_2 in flue gas delivered from each boiler
*32 Deck water seal
*33 S.W. supply to deck water seal from 6
*34 Deck water seal overboard discharge

* *Added later. See Section II*

Fig. 1 shows the prototype inert gas system installed in 1961 on *British Skill*, and contains the essential elements of any inert gas system. Briefly, flue gas is taken from the furnace uptakes and drawn into a scrubber (7) by a fan (10) and then discharged to the deck distribution system/vapour main. Safeguards are provided in the form of isolation and non return valves (13, 14 and 32) to prevent hydrocarbon gases returning to the engine room. An additional safeguard is provided by the water seal incorporated in the scrubber.

When liquids are discharged from a cargo tank, inert gas is delivered at a slight overpressure to fill the resulting void to prevent the ingress of air. When liquids enter a cargo tank, inert gas is displaced through the vapour main to the top of the mast.

A purge pipe (19) is fitted in each cargo tank in order that inert gas entering the top of an empty tank may displace gases from the body of the tank via the purge pipe. Each purge pipe extends to within 450 mm of the tank bottom and is positioned as remotely as possible from the gas inlet pipe.

The principle of inerting is basically simple. The development of BP inert flue gas systems has been directed to preserve this simplicity coupled with maximum reliability.

Whilst it is clear that the inert gas system can provide an important improvement in safety standards, the low oxygen content of the flue gas causes also a significant reduction in corrosion. The lower the oxygen content the better is the protection in respect of corrosion and safety.

In Part I of the paper which follows, emphasis will be placed upon the development of the system as a whole and its effect upon tanker operations. The design considerations and details of the individual components will be discussed in Part II.

PART 1—THE BP FLUE GAS SYSTEM AND ITS EFFECT ON TANKER OPERATIONS

1. HISTORICAL

1.1 *Inert Gas Systems in U.S. Oil Tankers*

The system of flue gas inerting of cargo tanks was first introduced by a U.S. oil company in 1925 but was abandoned after several years for a number of reasons. On their particular trade, which involved short voyages, frequent mopping of the cargo tanks necessitated fresh air venting and the inert gas system was rarely in use. It was considered that this engendered a false sense of security and doubts were raised regarding the value of the inert gas system as a safety measure on these ships. Consequently, in 1948 the system was removed by that company and only the closed loading characteristics and blower were retained. It should also be remarked that as these vessels were engaged in the products trade, a complex vapour system was used to prevent contamination of one cargo by the vapours of another.

In 1932 another U.S. company, Sun Oil of Philadelphia, decided to use flue gas inerting as a safety measure in all its seagoing tankers following a serious explosion in one of their ships. The system developed by Sun Oil was basically simple compared with earlier ones and has been successfully operated from the inception.

1.2 *Possibility of Corrosion Reduction*

Some increase in the rate of corrosion had been anticipated by Sun Oil when the system was first fitted owing to the presence of carbon dioxide. Several years later, it was realised that a reduction in the cargo tank corrosion had occurred.

The U.S. Navy has conducted experiments on the use of dehumidified flue gas to retard internal corrosion (Ref. 2). The use of dehumidified inert gas would appear to have had a strong corrosion inhibiting influence. Later experiments using humid inert gas on another U.S. Navy vessel showed a significant reduction in the quantity of scale formation.

Before fitting a prototype installation to a BP tanker vessel, members of the company visited the United States to obtain direct information regarding the corrosion of U.S. tankers. Safety aspects were considered simultaneously, and discussions were held with operators who had discontinued the use of inert gas. Both inerted and non-inerted vessels were examined.

The conclusion was reached that the rates of corrosion of both the inerted and the non-inerted vessels were significantly less than those which had been experienced in BP vessels. It was tentatively concluded that the use of inert gas on certain vessels was associated with lower rates of corrosion than on other U.S. vessels on similar trades. It was not possible to determine to what extent the comparison was influenced by variations in operational procedures such as the amount of tank cleaning or ballast carried. It was even less clear to what extent inert gas would provide a reduction in corrosion in BP vessels, which were usually engaged in different trading patterns from these U.S. vessels.

1.3 *Prototype System and Evaluation of Corrosion and Safety Aspects*

The BP prototype inert gas system was designed, taking into account the information obtained from the U.S.A. It incorporated much of the simplicity of the Sun Oil system but differed principally in the pressure characteristics of the gas delivery fan and the design of scrubbing tower.

Prototype inert gas systems were fitted on s.s. *British Skill* and on s.s. *British Sovereign* in 1961. At that time, *British Skill* and *British Sovereign* had been in service ten years and seven-and-a-half years respectively. Sister ships s.s. *British Talent* and s.s. *British Victory* respectively were selected as control ships for corrosion assessment. In February 1962 the 42 000 dwt tanker, s.s. *British Prestige* was fitted with an inert gas system during building. On this vessel, certain tanks were isolated from the inert gas system to allow direct comparisons to be made between inerted and non-inerted tanks.

During the period of corrosion assessment, ample operating experience was obtained using the inert gas system and the safety aspects were carefully studied. The tank atmospheres have been studied on selected vessels. Following a series of recent explosions on certain large tankers further investigations have been made to determine whether pockets of explosive mixtures could exist in the very large tanks of 215 000 ton vessels. The result of these experiments confirmed the confidence placed in the inert gas system by showing how the gas distribution varied within the tanks during each type of operation.

Since 1963, all new crude oil vessels built for the authors' company have been fitted with inert gas systems. These have included motor and steam ships. Fig. 2 shows the inert gas system on the 215 000 ton vessels which, when compared with Fig. 1, shows how the inert system has been developed.

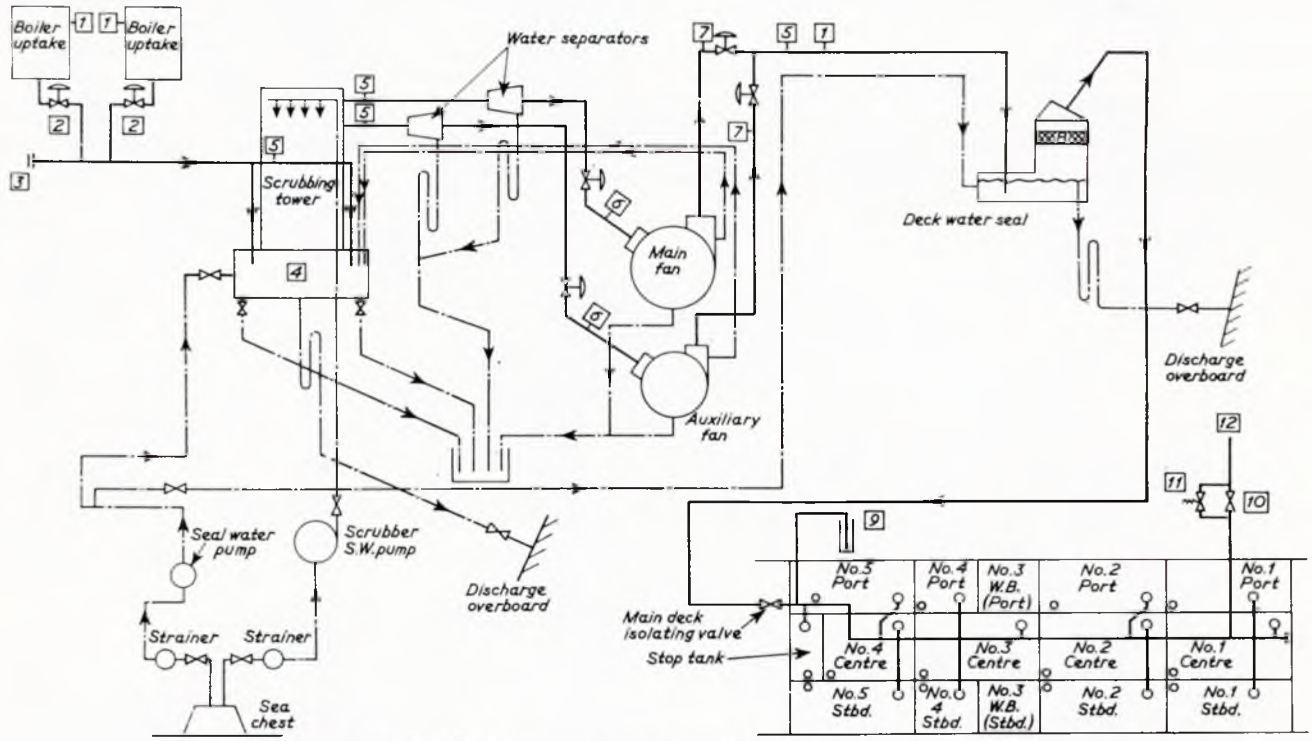


FIG. 2—*Inert gas system on 215 000 ton vessels*

1 Oxygen sampling point
2 Boiler uptake valves—remote operated from control room open/shut indicators provided
3 Blank flange for testing and gas freeing
4 Scrubbing tower water seal
5 Test connexions
6 Gas temperature switch
7 Control valve operated by controller in pump room entrance—shuts in event of air failure, fan stopping, scrubber water failure, or high gas temperature at scrubber outlet
8 Demister pad
9 Liquid pressure vacuum breaker
10 Riser isolating valve
11 Pressure/vacuum valve
12 Gauge screen flame arrestor

Note: one purge pipe fitted in each cargo tank

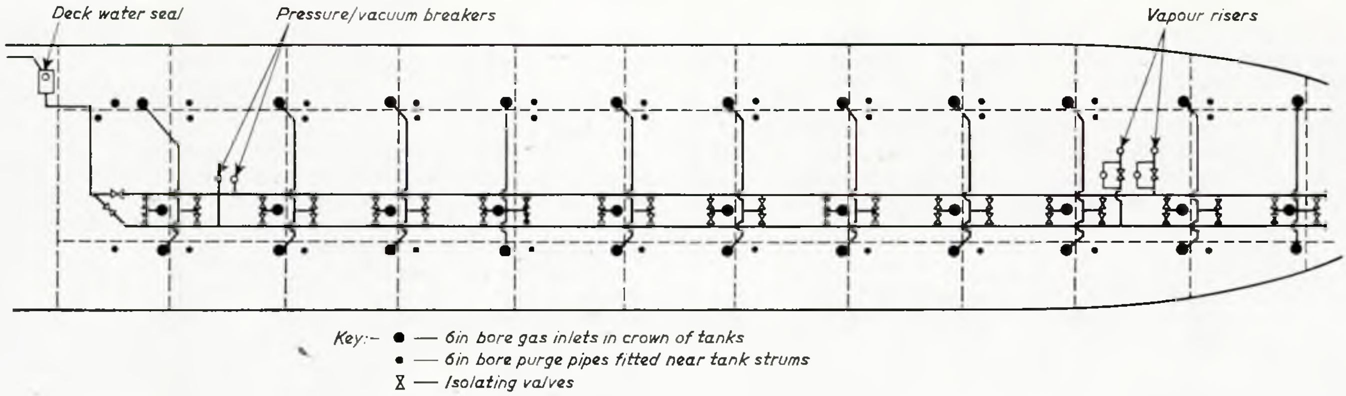


FIG. 3—*Product carrier deck system*

1.4 *Product Carriers fitted with Inert Gas System*

In 1968 the first product carriers fitted with inert gas systems were delivered to BP (Fig. 3). There had been some reluctance to fit a product carrier with inert gas in view of the complexity of the operations of these vessels, which undertake a large number of voyages a year with many different grades of cargo. However, a solution was found by providing two deck distribution lines, one for class A and one for class **B** and C cargoes.

The difficulties experienced on the product carriers have so far been much less than anticipated.

1.5 *Repairs Afloat*

Since 1968 a number of vessels have been repaired afloat in the inerted condition. Some have been drydocked in the inerted condition, without having to tank wash or gas free, subject to checks that a low level of oxygen existed in the cargo tanks. It should be mentioned that in these circumstances no repairs are allowed above the main cargo tanks.

1.6 *Patenting of System*

To ensure that, as a safety measure, the BP system would be available to the industry without payment of royalties the basic system is protected by British Patent 982791, 1965.

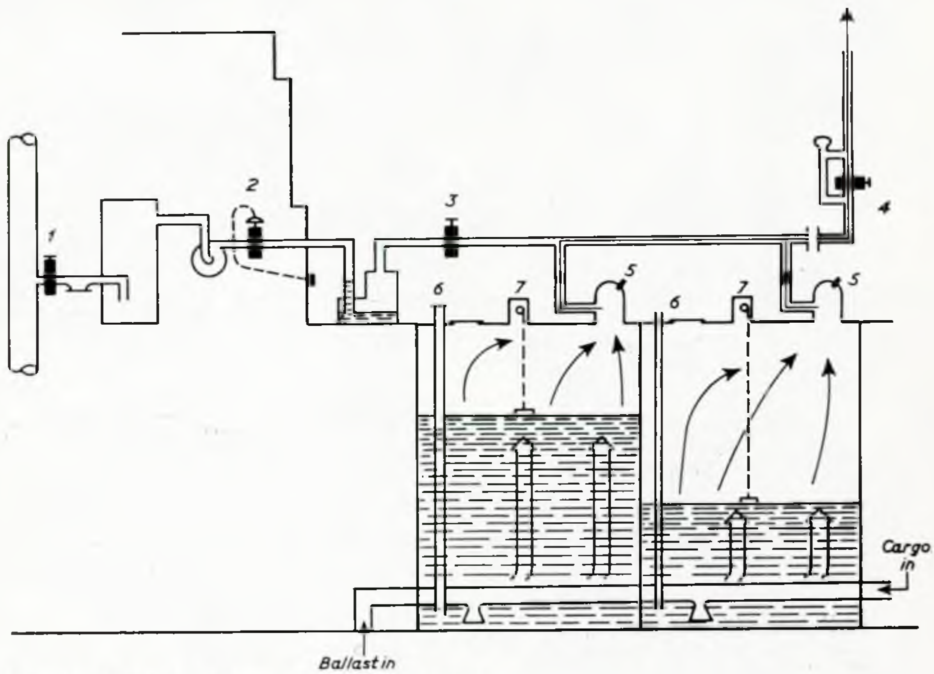
For the convenience of other shipowners, shipyards and the authors' company, a number of royalty free licences were granted to companies capable of designing, supplying and commissioning the inert gas equipment. Alternative designs of scrubbing towers, demisters, deck water seals, etc., have been developed as a result of this arrangement. Close technical co-operation has been maintained with the licencees in order to improve the reliability of the system in the light of service experience. Additional complexity has been discouraged.

The reliability of the system has been improved by the addition of a standby fan, a water seal to prevent the return of gases from the cargo tanks, and the use of better materials where necessary. Close personal contact has been encouraged between the shore staff and the seagoing staff, who, appreciating the improved safety standards, have operated the system well.

2. USE OF INERT GAS DURING TANKER OPERATIONS

A comprehensive instruction manual is issued to all inerted ships. The operations described here may appear to be complex, but they have been efficiently carried out by the ships' staffs on both crude oil ships and product carriers. The shore personnel at refineries and loading terminals, and those engaged at the repair yards have co-operated well in maintaining inert atmospheres in the tanks of these ships.

The operation of the inert gas system is best understood by reference to the diagrams. Additional explanatory matter is given below.



1 Boiler—uptake valves closed—inert gas fan stopped
2 Pressure—control valve shut
3 Main inert gas valve closed—system off
4 Mast riser valve open to atmosphere
5 Tank hatch deadweight pressure—relief valve in operating position (valve closed after loading)
6 Purge pipes closed
7 Mechanical ullaging devices set for gauging

FIG. 4—*Loading cargo or taking on ballast*

2.1 *Loading Cargo on Crude Oil Vessels* (See Fig. 4)

The vessel arrives at the loading terminal with all tanks inerted on the previous ballast passage. As the remaining ballast is discharged prior to loading, inert gas is fed to the ballast tanks.

When cargo is loaded into the vessel, the incoming liquids displace the inert gas from the cargo tanks through the vapour main and out to atmosphere through the mast vent. During this process the inert gas system is turned off, and isolated from the vapour main.

When loading is complete, the mast valve is shut. The cargo tanks are then allowed to breathe through the mast valve bypass which is fitted with a pressure/vacuum valve. If no residual pressure remains from the cargo loading, the tanks are then pressurised with the inert gas system. When the pressure has reached about 30 in W.G. the deck isolating valve is closed, and the inert gas system shut down.

2.2 *Loaded Passage*

During the loaded passage, the pressure above the cargo may increase, especially if cargo heating is being applied, and the pressure/vacuum valve relieves.

Over a period of days, the pressure in the tanks usually falls due to slight leakages from the hatches, Butterworth lids, etc. Diurnal variations in pressure occur due to temperature changes, and should the pressure fall below 4 in w.g. the system is started up and the pressure restored to about 30 in w.g. This operation takes about 15 minutes and the frequency may vary from once per day to once per week.

1 Main inert gas stop valve open; system in use
2 Mast riser valve closed
3 Pressure control valve set for maximum operating pressure during bulk discharge—set for low-pressure operation (about 10 in w.g.) if sounding manually after all cargo or ballast has been discharged or when finally stripping
4 Mechanical ullaging device in use when discharging bulk
5 Some mechanical ullaging devices unable to record last few inches during stripping if inconveniently positioned in tank
6 Manually dipping through purge pipe (slight positive outflow due to low-pressure operation of pressure control valve)
7 Alternative manual dipping through sighting port

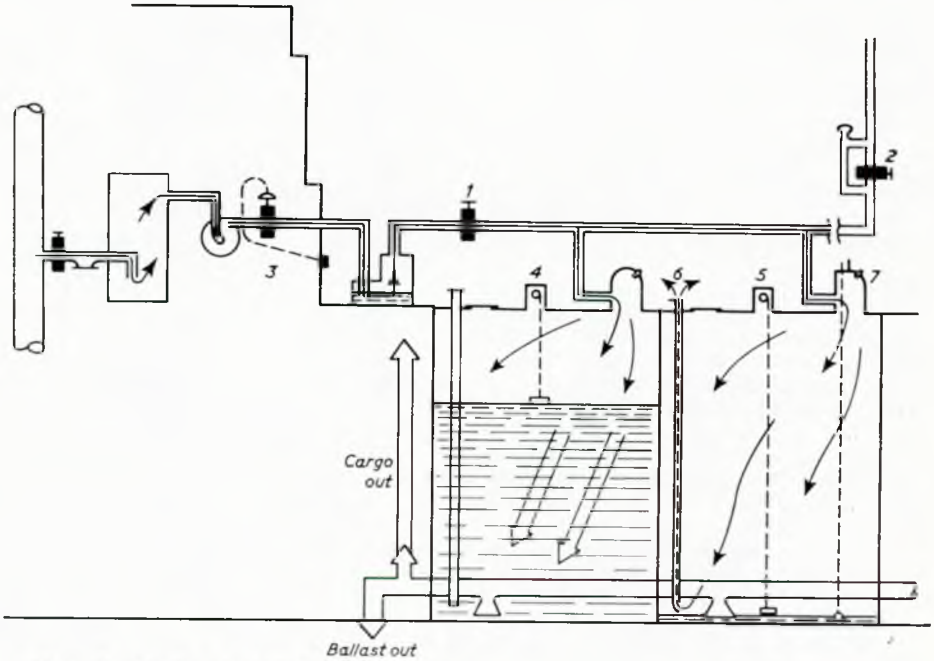


FIG. 5—*Discharging cargo or ballast*

2.3 *Discharging Cargo* (See Fig. 5)

During discharge of cargo, inert gas is delivered with slight over-pressure to the tanks. Contrary to practice when discharging non-inerted vessels, the mast valve is kept closed. The characteristics of the fan are selected so that a reasonable over-pressure is maintained above the cargo regardless of the rate of discharge. Even if the discharge ceased altogether, the inert gas fan is incapable of pressurizing the tanks beyond a safe limit. The presence of the deck seal prevents the return of hydrocarbon gases under nominal no flow conditions.

A liquid seal pressure/vacuum breaker (Fig. 6) is fitted on all vessels with closed loading facilities. On inerted vessels, because the mast vent valve is closed during discharge of cargo or ballast, there is an additional risk of a large vacuum being caused in the tanks if there is maloperation. If an extreme vacuum (or pressure) occurred, the liquid contained in the pressure/vacuum breaker would be expelled.

As the load on the boilers varies during discharge of cargo, it is necessary to watch the combustion control closely. During normal discharge conditions on a steamship, the oxygen concentration is about five per cent by volume. On very large crude oil carriers and on motor tankers where the boiler capacity is matched more closely to the cargo pumping rate, lower oxygen figures are more likely.

Mechanical ullage gauges facilitate the checking of progress. However, as these gauges do not cover the last 2 in of sounding,

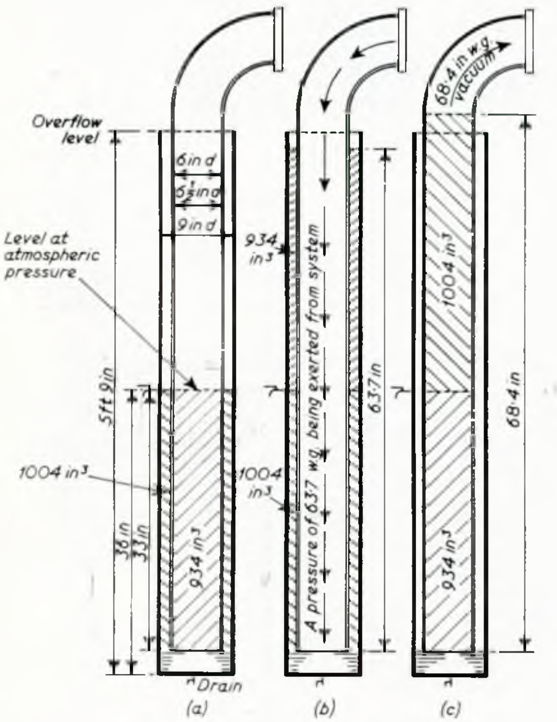


FIG. 6—*Principle of liquid pressure/vacuum breaker (drawn for 28 000 dwt ship)*

"dips" are taken through the purge pipe or ullage plug whichever is nearest to the after end of the tank to determine whether a particular tank is drained. A pressure controller is used to reduce the general pressure in the system, and thus make this operation more convenient.

2.4 *Ballasting* (See Fig. 4)

When the discharge of cargo has been completed, ballast is pumped into some of the cargo tanks to put the vessel in a seaworthy condition. The operation of the inert gas system at this time exactly corresponds with loading cargo, detailed above.

Some vessels are fitted with the facility to take on "dirty ballast" whilst discharging cargo. In this case, the inert gas system is left fully operational, but to prevent pressure building up in the inert gas main to the extent of lifting the P.V. valve or blowing out the liquid vacuum breaker, the mast head vent valve is opened. If the pressure then falls below about 5 in w.g. there is a possibility of air entering the system and the mast head valve should be adjusted until the pressure in the vapour main rises to about 18 in w.g. If ballasting finishes first, the mast head vent should be shut and the inert gas kept running until cargo discharge is completed.

2.5 *Purging*

The term 'purging' is used in this paper to mean the process of passing inert gas through an empty tank. In this system, the provision of a separate purging pipe in each tank avoids the operational complications which may result from using the cargo suction piping to exhaust the gases.

Having started up the inert gas system, it is only necessary to open the appropriate purge pipe lids. This allows the gas delivered at the top of the tank to dilute and displace the tank atmosphere through the purge pipe to deck. (As the gases are emitted at high velocity, the rapid dilution with air of any hydrocarbon gases is achieved outside the tank.)

During purging, the oxygen content of the emitted gases is measured at the purge pipe. When the oxygen content is within one per cent of that being supplied, and less than five per cent by volume, purging may stop. The time required to inert a tank initially containing fresh air corresponds to three or four changes of atmosphere.

The following objectives are achieved by purging:

i) the primary inerting of empty tanks;
ii) the rapid restoration of a satisfactory inert atmosphere, if for any reason poor quality inert gas was present;
iii) the reduction of the concentration of hydrocarbon gases.

For these reasons, it is prudent to purge after discharge of cargo, prior to tank washing, and before and after ventilating a tank with fresh air.

2.6 *Tank Washing* (See Fig. 7)

Prior to washing, the tanks are purged with flue gas of low oxygen content. If time does not permit all tanks to be purged before washing commences, some tanks can be purged whilst others are being washed. The pressure controller may be set to give a convenient pressure level during the tank cleaning operation.

The presence of washing water vapour often obscures the tank bottom on non-inerted vessels. The mist present during the tank washing of inerted ships is denser and more persistent. Improvements in scrubbing towers and demisters have led to a higher reduction of solids from the flue gases and the haze on later ships is less persistent.

The washing cycle is determined by experience on individual ships. The results must of course be checked in order to avoid any oil pollution, and occasionally tanks may have to be vented for entry.

2.7 *Venting and Gas Freeing*

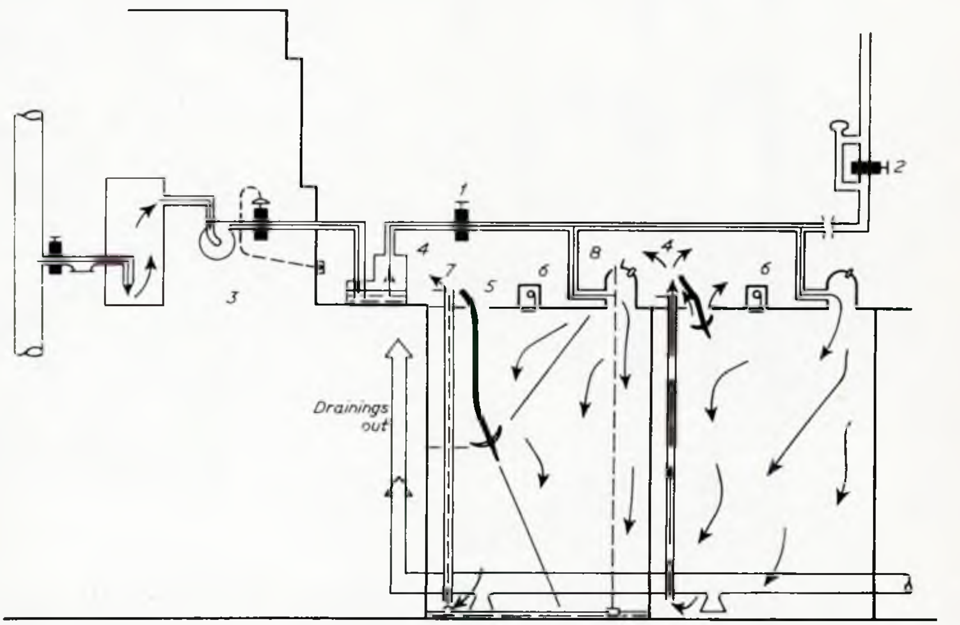
After the pressure in the inert gas main has been reduced to atmospheric, spade blanks are inserted into the branch lines to isolate the tanks to be vented with fresh air (Fig. 8). Portable vent fans, mounted in cleaning holes are normally used, and the purge pipes are opened to prevent pockets of gas remaining at the lower levels. An oxygen content of 21 per cent by volume, as. measured at the purge pipe, is required before entry is permitted

Before re-inerting, the spade blanks must be removed before the hatches can be closed. This precaution minimizes the risk of subsequent pressurization when the tanks are filled.

2.8 *Measurements*

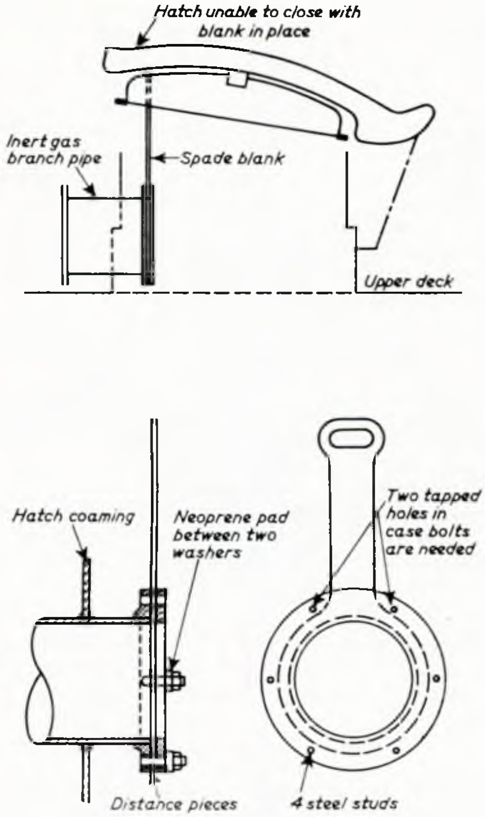
The oxygen content in the cargo tanks is measured and recorded. Until satisfactory instruments for measuring oxygen became available, CO_2 was also measured. Portable instruments, such as the Servomex oxygen meter or Fyrite oxygen and carbon dioxide analyser have been used. The more complex Orsat apparatus was used for this purpose but its use has now been discontinued. All these instruments give the percentage by volume of the gas to be measured on a water free basis.

As the atmosphere in the ullage space during the loaded voyage consists mainly of hydrocarbon gases and nitrogen, the oxygen or carbon dioxide content of the ullage spaces is not



1 Main inert gas stop valve open—system in use
2 Mast riser valve closed
3 Pressure—control valve set for low pressure operation (about 10 in W.G.)
4 Purge pipe opened to release pressure before opening tank—washing aperture
5 Tank—washing aperture muffled with sand bags to prevent unnecessary escape of gas
6 Mechanical-ullage device withdrawn into trunk
7 Dipping through open purge pipe
8 Alternative dipping through sighting port if more suitably positioned than purge pipe

FIG. 7—*Tank washing using portable machines*



BLANK FLANGE ARRANGEMENT

FIG. 8—*Spade blank arrangement on crude oil vessels*

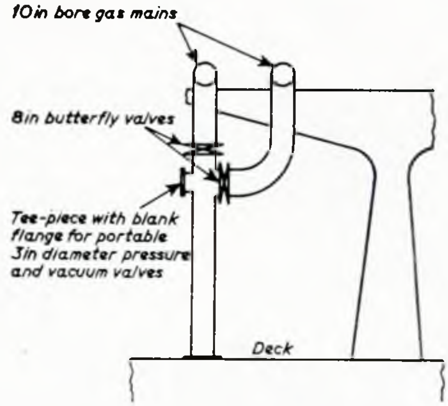


FIG. 9—*Arrangement of provision for fitment of portable pressure/vacuum valves when carrying special boiling spirits and white spirits*

normally measured.

M.S.A. explosimeters are supplied to all vessels.

The pressure over the cargo and at the fan are monitored, as is the carbon dioxide or oxygen content of the boiler flue gas.

The oxygen contents of empty tanks are recorded after discharging cargo or ballast, after purging, tank cleaning, and ventilation.

The experiments described in the section on "Safety Considerations" showed that the readings taken at the purge pipes were reliable indications of the conditions prevailing in the tanks themselves. This is not to say that the readings taken at the purge pipe were necessarily typical of those found at other positions, but it was found that safe atmospheres existed at all parts of the tank when the readings at the purge pipes were within one per cent of the gas compositions being supplied.

2.9 *Effect of Inert Gas on the Operations of Product Carriers*

In a product carrier it is necessary to segregate the vapours of one cargo from another. Consequently, duplicate gas mains have been provided so that vapours of class A petroleum parcels may be isolated from vapours of class B and C petroleum parcels. No segregation is provided between the vapours of class B and C parcels.

Each cargo centre tank is connected to both gas mains through a branch pipe and Y-piece. Each pair of wing tanks is similarly connected (Fig. 3). The tanks nominated for class A petroleum parcels are connected to the port vapour main and isolated from the starboard main. Similarly the tanks nominated for class B and C parcels are connected to the starboard gas main and isolated from the port main.

When inert gas is supplied to the tanks during discharge of cargo, no mixing of the vapours should take place.

Provision has been made for products such as special boiling point spirits, and white spirits which absorb odours from other products. When spirit cargoes are carried, portable pressure/vacuum valves are fitted in place of blank flanges on the vapour branch pipes of any tanks nominated for these special products (Fig. 9).

When three different vapour grades are loaded, the tanks nominated for spirit should be loaded either before or after the class A, B and C petroleum parcels, using the appropriate gas main.

When the loading of each tank containing SBP or white spirits is completed, each of these tanks should be isolated from both inert gas mains. The tanks containing spirits then 'breathe' during the loaded passage via the portable relief valves.

Although these tanks containing spirit are thus disconnected from the inert gas system, in emergency they may be reconnected by simply opening the branch valves.

Before discharging cargo, when three vapour grades are carried, the port and starboard vapour mains are first pressurized by inert gas and finally the spirit tanks are connected to the vapour system. To date, no vapour contaminations have occurred.

Tank inspections by refinery personnel are more frequent and exacting on a product carrier than on a crude oil carrier. However, the tanks are often accepted as a result of hand dipping through the purge pipes. These are placed at the aft end of each compartment in order to be certain of detecting any residual liquids. It is sometimes necessary for the ship or shore personnel to sight the cargo tank bottom, and when the pressure on the tank has been released the hatch lid may be opened.

If the cargo inspector requires to enter the cargo tank then this must be gas-freed by isolating it from the rest of the system, and vented with portable fans. During this process the purge pipe is opened to assist in efficient venting.

The effect of carbon dioxide on certain products such as jet fuel is undesirable if it is absorbed in large quantities. Tests carried out some time ago in America indicated that negligible quantities of CO_2 were absorbed when the inert gas blanket system was used over jet fuel. Sulphur dioxide which could affect the quality of certain products, is only present in the flue gas in small quantities.

3. SAFETY CONSIDERATIONS

3.1 *General Considerations*

The inert gas system is now internationally accepted as a safety feature, and it meets British Statutory requirements for a fixed fire smothering system. (The Merchant Shipping Act) (Fire Appliances Rules 1965, Rule 60). On the majority of vessels fitted with the inert gas system in the authors' company, no other fixed fire smothering system is fitted for the cargo tank protection.

The statutory requirements call for a minimum system capacity, equal to an hourly rate of 25 per cent by volume of the largest tank. As the capacity of the inert gas system is related to the cargo discharging rate, this has resulted in a large margin over that required for statutory purposes. The time to change the atmosphere of the cargo tank once, using the inert gas system, varies from 20 minutes on a small crude carrier to about

80 minutes on a large crude carrier. This compares with the statutory requirement of 240 minutes per atmospheric change within a tank.

Unlike other fixed smothering systems, the inert gas system is in use at all times and therefore can prevent fire or explosion within the tanks. Other fixed systems are fitted in order that a fire may be contained after an explosion has occurred. Unfortunately, the initial explosion may cause loss of life and sometimes loss of the vessel itself. There is also the probability that the fire fighting system itself may be rendered useless by the explosion.

The operation of the BP inert gas system is therefore directed towards the *prevention* of explosion and fire within the tanks. In the unlikely event of a fire occurring on an inerted tanker, the inert gas system would be no less effective in preventing the fire reaching the remaining tanks than other systems.

It is, of course, necessary to provide fire *extinguishing* equipment on inerted vessels, if, for example, an oil spillage at the manifold ignited on the deck. In this event, the inert gas system provides the best protection for the tanks themselves, but other means must be used to prevent damage to the remaining parts of the vessel. The provision of portable foam making equipment, sited strategically, in conjunction with the statutory fire main are sufficient for this purpose on inerted vessels. Although a deck fire may be extinguished or contained by fixed foam installations, these have strictly limited capacities. Eventually, it is more than likely that the fire would have to be tackled with water, and provided no damage to the fire main or pump had occurred, this at least is in unlimited supply. It is therefore considered unnecessary to supply an additional *fixed* extinguishing system for the decks of inerted vessels.

As alternatives to the inert gas system, fixed foam, CO_2 and steam smothering systems are cheaper to supply and maintain and do not interfere with the operations of tankers, but they suffer from major deficiencies in comparison with the inert gas system. It is outside the scope of this paper to discuss these in detail, but the following deficiencies are noted:

i) they all have strictly limited capacities;
ii) they have little practical fire prevention value;
iii) thorough testing may be not only relatively infrequent, but because of (i), often impracticable;
iv) a tank explosion, which could have been prevented by inert gas, may destroy the distribution system and the fire main—the high risk of further tank explosions would make the task of the fire fighting team more hazardous;
v) all require initiation and delay as compared with the inert gas system.

The above remarks are made in the context of a properly designed, maintained and operated inert gas system, but no system is foolproof. Maloperation of the inert gas system will and does occur from time to time. As in all safety matters this is best prevented by the provision of the most simple system, the establishment of a regular routine, and the education of personnel. This is no easy task in a large fleet, but we consider that the occasional occurrence of maloperation is no reason to delete or reject inert gas systems. Our experience shows that maloperations are exceptional, and that the average oxygen content within the cargo tanks is well below that required for combustion.

The fitting of an inert gas system is complementary to the intelligent observance of the safety regulations, for which there is no substitute. The exclusion of possible ignition sources through design and regulation is of prime importance. The inerting of the tanks provides protection against human negligence during all stages of tanker operation.

3.2 *Hydrocarbon Gases and Limits of Flammability*

The vapours from volatile petroleum cargoes are mainly mixtures of the individual hydrocarbons of the normal paraffin series. The concentration and the proportion of each component varies according to the type of cargo and other factors including the effects of shipboard operations.

As an inert gas such as nitrogen, steam or carbon dioxide is added to mixtures of hydrocarbon gases and air, the flammable range becomes progressively narrower. Data on a large number of gases and volatile liquids is given in Refs. 3 and 4. The limiting dilutions may be conveniently expressed in terms of the oxygen content below which no mixture is flammable. These limits are summarized in the table below, together with the limiting hydrocarbon content in atmospheric air.

TABLE I

Hydrocarbon	Limiting O_2 content for flammability, per cent volume: N_2 as diluent	CO_2 as diluent	Limiting hydrocarbon content in air, per cent volume: L.E.L.[1]	U.E.L.[2]
Methane (CH_4)	12·1	14·6	5·0	15·0
Ethane (C_2H_6)	11·0	13·4	3·2	12·5
Propane (C_3H_8)	11·4	14·3	2·4	9·5
Butane (C_4H_{10})	12·1	14·5	1·8	8·4
Pentane (C_5H_{12})	12·1	14·4	1·4	7·8
Hexane (C_6H_{14})	11·9	14·5	1·2	6·9

[1] Lower explosive limit [2] Upper explosive limit

Each hydrocarbon gas component contributes to the flammability of a mixture with air in proportion to its concentration. The flammable limits of the mixture can be calculated when the concentration of each constituent is known (Ref. 3).

The following table gives examples of the concentrations of

TABLE II—COMPOSITION AND FLAMMABLE LIMITS OF HYDROCARBON MIXTURES IN LOADED AND EMPTY CRUDE OIL TANKS

Time of sampling	Before discharge	After discharge	Before washing	After washing
	Per cent volume air-free basis			
Methane CH_4	25	20	6	5
Ethane C_2H_6	22	18	11	9
Propane C_3H_8	30	30	26	23
Butanes C_4H_{10}	16	20	27	28
Pentanes C_5H_{12}	6	8	18	20
Hexanes C_6H_{14}	1	4	12	15
	Per cent volume in air			
Lower flammable limit	2·6	2·4	1·9	1·8
Upper flammable limit	10·6	10·0	8·9	8·7

individual hydrocarbon present in cargo tank spaces of a crude oil carrier. Calculated lower and upper flammable limits for these hydrocarbon gas mixtures are shown.

The usual limits of flammability quoted as between 2 per cent and 10 per cent will encompass the majority of compositions likely to occur on crude oil vessels. However, it is considered that when generalising on the probable extremes of flammability, a margin of safety should be included, especially for the L.E.L. Values of 1·3 per cent and 11·5 per cent for the L.E.L. and U.E.L. respectively should cater for the majority of cases on both crude oil and refined products carriers with a margin of safety.

It should be noted that these remarks are confined to mixtures of petroleum gases. When special products are carried, it is recommended that Ref. 3 and Ref. 4 are consulted, especially when a single gas is mixed with air.

cular situation inert gas would fail to live up to the reputation of a cure all which some may claim for it. When the tanks are empty, however, the ability to reduce the hydrocarbon gases in the tanks by purging with inert gas makes it possible to prevent fire or explosion in the event of collision.

The value of purging before tank washing or ventilation will now be quite clear. Furthermore all other practical methods for ventilating a tank containing hydrocarbon gases will result in the formation of flammable atmospheres within the tank at some time during the procedure.

As may be inferred from the flammability diagram, the gases emitted during the purging process may become momentarily flammable in air. These gases are expelled at high velocity which results in rapid dispersion and a negligible risk of a persistent flammable cloud. The atmosphere within the tanks themselves

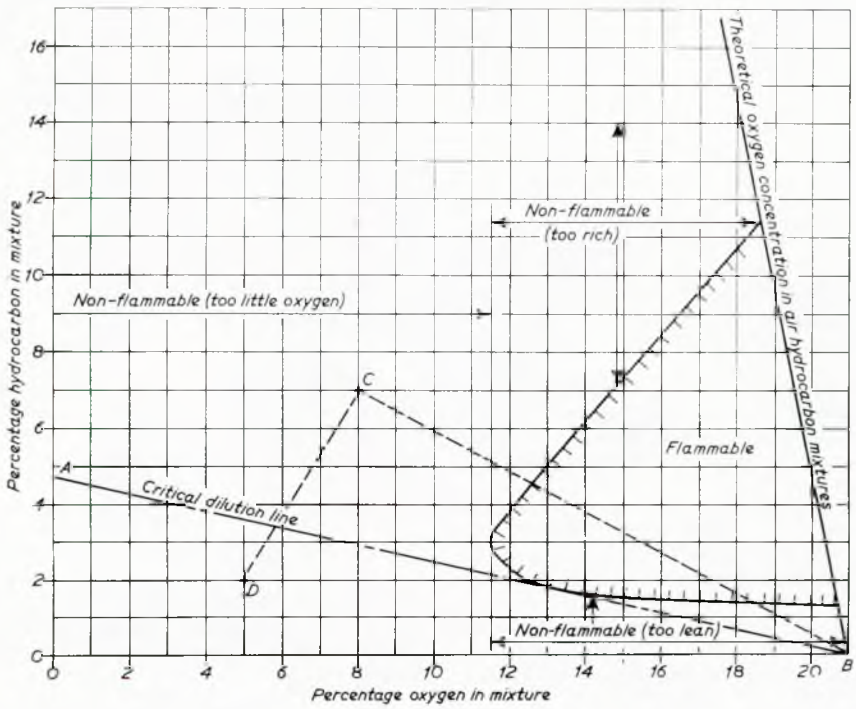


FIG. 10—*Limits of flammability of hypothetical hydrocarbon nitrogen/oxygen mixtures*

3.3 *Flammability Diagram for Inert Gas Hydrocarbon Mixtures*

Fig. 10 shows how the limits of flammability progressively narrow as the oxygen content reduces, and assumes conservative values for the envelope curve. The line AB represents the critical dilution line when inert gas/hydrocarbon mixtures are suddenly diluted with air. If the hydrocarbon content for a given oxygen content lies above this line, as does point C, then the mixture would dilute with air through the flammable range (line CB).

On the other hand, if the mixture defined by the point C were purged with inert gas of high quality until the oxygen and hydrocarbon contents reduced below the critical dilution line, as does point D, the subsequent dilution of this mixture with air cannot cause a flammable condition to occur. This diagram is particularly useful when considering the effects of collision, ventilation with fresh air, and purging with inert gas.

The value of the inert gas system in collision, other than for purposes of confining the possible fire to the breached tank, depends on whether the concentrations of the hydrocarbons and oxygen lie above or below the critical dilution line AB. It also depends on the size of the breach and whether extensive mixing occurs with the outside air. In the loaded condition, when the hydrocarbon content is usually high, the atmosphere is likely to pass through the flammable range during dilution, so that a period must exist when there is risk of explosion. In this particular situation inert gas would not support combustion from whatever cause.

It is to be hoped that this section will have helped to remove the impression that the inert gas system only provides an inert blanket over an atmosphere which is rich in hydrocarbons. The flammability diagram also illustrates that there is a wide range over which satisfactory inert conditions can exist. Whilst optimum conditions of combustion and operation are most *desirable*, we cannot agree with the view expressed authoritively in Ref. 5, that such conditions are *essential* to the viability of the inert gas system.

3.4 *Tank Atmospheres on Inerted and Non-Inerted Vessels*

The early investigations into the tank atmospheres of smaller vessels showed the inert gas systems were at all times effective (Ref. 6). However, the explosions referred to earlier on some non-inerted 200 000 dwt tankers drew attention to the possibility of conditions in very large tanks differing from those in smaller. Consequently it was felt essential to verify that pockets of flammable gases could not be retained in isolated corners of such tanks despite the use of accepted ventilation and purging procedures. Tests were therefore carried out on two 215 000 dwt vessels directed specifically towards the distribution of the gases composing the tank atmosphere after discharge of cargo and during the ballast passage.

3.4.1 *Gas Concentrations in Cargo Tanks*

Measurements of the gas concentrations within cargo tank spaces have shown that the tank atmospheres are not always homogeneous, and that concentration gradients exist. The following table gives some typical vertical ranges in hydrocarbon concentrations measured in a very large crude carrier. The following readings were taken in unpurged tanks.

TABLE III— VERTICAL RANGE OF GAS CONCENTRATIONS DURING VARIOUS OPERATIONS

Tank	Total hydrocarbons per cent volume			
	Before discharge	After discharge	Before washing	After washing
1 centre	77	4–27	2–15	4–6·5
2 centre	73	0·5–7	3·5–5	4
4 centre	74	0·5–13	1·5–9	2–4·5
4 port	65	2·5–16	1–6	1·5–3
4 starboard	65	1·5–24	1·5–6	2–3·5
5 port	71	0·5–18	1·5–5	1·5–3
5 starboard	65	2–30	0·5–11	1–3

The concentration gradients observed in empty tanks form during the discharge of cargo, when the rich layer above the cargo is only partially diluted by the incoming gases. If the incoming gas is air, then some mixtures will be formed which are flammable. When the incoming gas is inert, then the mixtures so formed cannot be flammable even though strong layering may have taken place.

If the tanks are left undisturbed after discharge of cargo, then these layers will gradually disperse throughout the tank volume. Conversely it is important to realise that gas mixtures in an undisturbed tank *do not* decompose into layers consisting of the individual components of the mixture.

It also appears that after the discharge of cargo, the evolution of hydrocarbon gases is very low. During tank washing the principal effect is that the atmosphere becomes more uniform, even though the hydrocarbon gas content may increase by about 1 per cent.

Reference to Table 2 shows that there is a tendency for the proportion of lighter gases, such as methane and ethane, to be reduced during the ballast voyage. As the heavier gases then form larger proportions of the total hydrocarbon content, both the upper and lower flammable limits tend to reduce in terms of the percentage of hydrocarbon gases present.

The gas concentrations during each particular operation will be considered below.

3.4.2 *Loading Cargo*

3.4.2.1 *Non-Inert Vessels*

During loading of crude oil, a concentrated layer of hydrocarbon gas forms above the liquid surface of the cargo. This layer rises with the oil with little change in its vertical concentration gradient. The gas expelled from a tank which is initially gas-free will consist of air in the early stages of loading, and will remain so until the dense gas layer reaches the vent outlet. The hydrocarbon concentrations in the vent gas will then increase rapidly as the layer itself is vented. Gas expelled from a non gas-free tank will contain appreciable hydrocarbon concentrations from the start, and again these will increase at the end of loading as the surface layer is vented.

Examples of the variation of vent gas composition relative to the true ullage of the oil are shown in Fig. 11 for both gas-free and non gas-free tanks. It may be noted that the tank atmospheres are within the flammable range for an appreciable part of the loading period (Ref. 7).

3.4.2.2 *Inerted Vessels*

In an initially inerted tank, the atmospheres within the tanks are safe throughout the loading period.

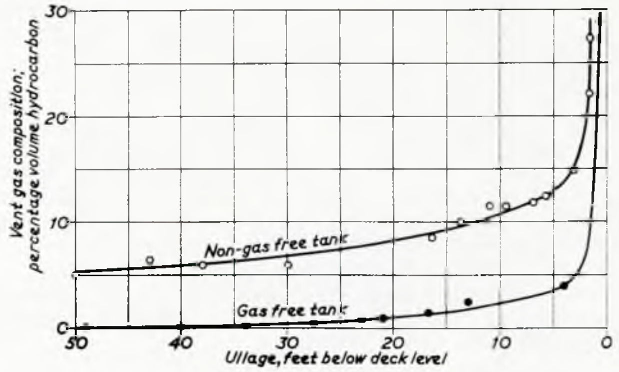


FIG. 11—*Vent gas composition during loading of Kuwait crude oil* (British Destiny, *January 1967*).

The dispersion of vent gases to avoid the formation of flammable hydrocarbon gas/air mixtures about the decks of tankers during loading has been the subject of study by the International Oil Tanker Terminal Safety Group (Ref. 8). Provided the recommendations made with regard to the siting of tank vent outlets are followed, the risk of ignition of the diluted vent gases flashing back to the tanks should be minimal. On an inerted tanker, such a flash could not ignite a tank. It will have been noted that the provision of an inert gas system implies closed loading facilities, which in themselves improve the standard of safety.

3.4.2.3 *Loaded Passage*

During this period, hydrocarbon concentrations in the ullage spaces are normally high and oxygen concentrations low, and thus conditions are relatively safe. Air drawn in during 'breathing', when the temperature falls, may dilute the atmosphere sufficiently to make it flammable. This can be avoided by maintaining a positive pressure within the tanks with inert gas.

3.4.2.4 *Discharging Cargo*

Tables 4A and 4B show gas concentrations in the tanks of non-inerted *British Statesman* and inerted *British Sovereign* before and during discharge of crude oil. These results show that all atmospheres in the inerted ship were safe, in contrast to the non-inerted ship where atmospheres were in the flammable range.

Table 5 demonstrates that on completion of discharge, tanks contain stratified gas layers which can persist for several days.

3.4.2.5 *Ballast Passage*

The tanks may contain atmospheres varying between too lean and too rich to be flammable. There are three basic options open to the operator when considering the relatively hazardous tank cleaning operation.

These are:

a) i) provide an atmosphere in the tanks which is everywhere inert;
   ii) as (a) i) but with the hydrocarbon gases sufficiently lean to allow the tank to be vented without dilution through the explosive range, which gives an additional margin of safety should the tanks be opened—any gases escaping through deck openings will be non-flammable;

b) provide an atmosphere in the tanks which is everywhere too lean to be flammable;

c) provide an atmosphere in the tank which is everywhere too rich to be flammable.

The key word in all three options is "everywhere". Uniformity of atmosphere is not essential, provided that gas concentrations within the flammability envelope are not present. All three methods seek to prevent explosions and recognise that all sources of ignition cannot be eliminated. The question arises of how to determine in practice if safe atmospheres exist in all parts of the tanks with all three methods.

TABLE IVA—NON-INERTED SHIP S.S. *British Statesman* 23.5.61 AT KENT BEFORE AND DURING DISCHARGE OF IRAQ (BANIAS) CRUDE

Time	Tank	Ullage	O_2 percentage vol.	N_2 percentage vol.	Total hydrocarbons percentage vol.	Remarks	
09.55	8CP	5 ft 3 in	10·2	54·6	35·2	Before discharge	
12.00	,,	5 ft 3 in	20·9	74·8	4·4	During discharge	All these
14.10	,,	12 ft 0 in	20·5	73·0	6·5	,, ,,	gas
16.50	,,	40 ft 0 in	20·6	74·9	4·3	,, ,,	mixtures
18.00	,,	49 ft 9 in	21·0	76·0	2·8	,, ,,	are
19.25	,,	54 ft 10 in	20·7	74·8	4·5	,, ,,	flammable

TABLE IVB—INERTED SHIP S.S. *British Sovereign* 5.2.62 AT KENT BEFORE AND DURING DISCHARGE OF KUWAIT CRUDE

Time	Tank	Ullage	O_2 percentage vol.	CO_2 percentage vol.	N_2 percentage vol.	Total hydrocarbons percentage vol.	Remarks	
10.00	8C	4 ft 0 in	2·1	3·0	47·3	47·5	Before discharge	
17.20	,,	14 ft 0 in	4·0	9·9	78·8	7·3	During discharge	None of
18.00	,,	22 ft 9 in	3·8	9·8	76·2	10·2	,, ,,	these
18.30	,,	30 ft 0 in	3·9	11·0	83·0	2·1	,, ,,	mixtures
19.00	,	36 ft 0 in	3·9	11·4	83·0	1·7	,, ,,	are
19.30	,,	42 ft 0 in	3·9	11·1	83·4	1·6	,, ,,	flammable
20.30	,,	49 ft 9 in	4·0	11·4	83·0	1·6	,, ,,	

3.5 *Tests on Very Large Crude Carriers*

To clarify these questions, venting and purging experiments were carried out on two 200 000 ton vessels. Sampling points were arranged at various depths and at different positions in the length and breadth of these very large tanks. Experiments were carried out with clean tanks and later when hydrocarbon gases were present.

3.5.1 *Mode of Replacement of Gas Atmospheres*

It was shown that when the heavier gas was supplied from above the tank contents, the dominant process of removal was by mixing and dilution. When, however, the lighter gas was introduced above the more dense contents of the tank, the tank atmosphere was replaced predominantly by a displacement and layering process. The latter process implies a stable boundary between the two gas mixtures, and in theory only one atmospheric change would be necessary to remove the original gas contents. The stability of this layer varied from test to test, so that uniform atmospheres were obtained in not less than 1·5 atmospheric changes. It should be stated that when the gas is supplied at high velocity, the stable boundary is destroyed and mixing takes place. When mixing took place three or four atmospheric changes were necessary, and this is in line with the simple mixing theory.

TABLE V—HYDROCARBON PERCENTAGE VOLUME MEASURED BY MSA GASCOPE. Showing persistence of a rich layer of hydrocarbon near the bottom of a centre tank on a 215 000 ton tanker (Ship A. Tank 3C, 27 228 m^3. Discharge temp. 22°C)

Time after discharge	Depth (ft) below deck level					
	2	20	35	55	70	88*
0 hr–18 min	3	3	3	3	3	54
1 hr–20 min	3	3	3·5	3·5	3·5	52
4 hr–38 min	3·5	4	4	4	4	49
9 hr–12 min	4	4	5	5	5	44
13 hr–20 min	4	5	5	5	5	42
28 hr–00 min	7	7	7	7	7	20
39 hr–33 min	7	7	7	7	7	18
52 hr–00 min	6	7	7	7	7	12
63 hr–00 min	6	7	7	7	7	9

* Values typical of bottom 10 ft of tank

The following table shows the dominant processes in replacement of tank atmospheres during purging and ventilating operations on board Ship A and Ship B. Ship A was fitted with purge pipes, but on Ship B the gas was supplied from the cargo pipe lines and exhausted through the vapour main.

During these tests, it was observed that very slight differences in density were sufficient to determine the mode of replacement of the gas atmosphere. The presence of one per cent hydrocarbon gases in the tank atmosphere was sufficient to produce the required difference in density.

3.5.2 *The Importance of the Positions of the Gas Inlets and Exhausts*

The displacement process accomplishes the replacement of the tank atmosphere in a shorter period, but care must be taken to position the tank outlet remotely from the inlet, particularly in the vertical plane. The provision of a purge pipe extending close to the tank bottom is considered essential when the gases are supplied at deck level. Although the gases could be displaced alternatively through the cargo piping to the manifold, this may interfere with other operations.

The purging gas in some systems is delivered by the cargo suction piping and exhausted into the vapour main. Conditions conducive to displacement can also exist with this method, and care must be taken to avoid using a low level bulkhead valve to exhaust the gases between adjacent tanks without also using a deck level exhaust position.

The importance of the vertical separation of supply and exhaust positions has been demonstrated by tests on Ship A. It was shown that a tank, could be inerted satisfactorily without the use of the purge pipe, the inert gas being exhausted through a tank cleaning hole. The results showed that the replacement had been achieved by a mixing process.

When, however, a similar tank was vented with fresh air supplied by the inert gas fan, a displacement process resulted. Short circuiting of the incoming air to the cleaning hole resulted, and it proved impossible to ventilate the lower half of the tank by this method. The oxygen content at about half depth changed from 19·5 per cent to 8 per cent over a depth of four feet, thus establishing the physical existence of a relatively narrow boundary.

These tests were repeated using the purge pipe to exhaust the gases and all levels of the tank were vented satisfactorily (Fig. 12).

3.5.3 *Gas Layers and the Effect on the Routine Monitoring of Tank Atmospheres*

This latter result has direct application to other conditions when hydrocarbons are present, and when displacement by air or inert gas is probable. Fig. 13 shows the removal of hydrocarbon gases by inert gas using the purge pipe. It will be observed that as the interface between the incoming gas reaches each depth, the concentrations change rapidly. It may also be remarked that the readings at the purge pipe exits, or 80 ft depth are still high until one hour before the operation finished. Fig. 13 illustrates also that readings taken from the middle of the tank could be misleading if used to determine when ventilation is complete.

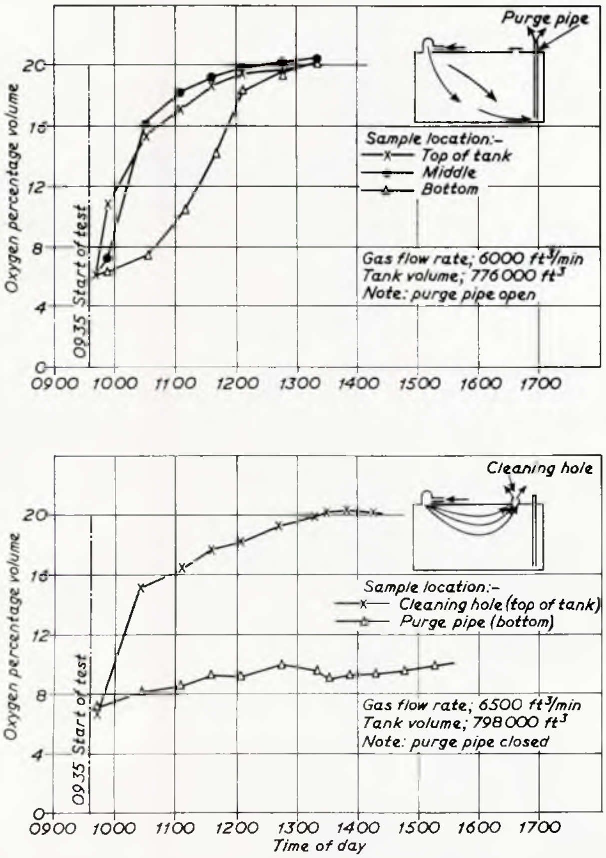


FIG. 12—*Ship A venting inerted tanks with fresh air, 6 April 1970*

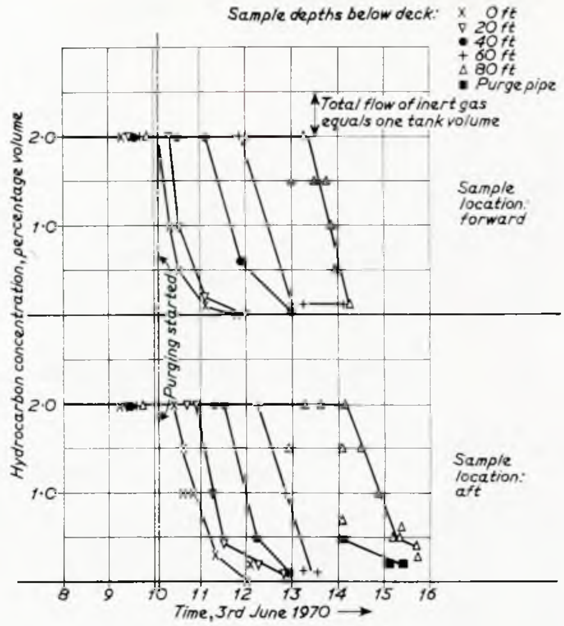


FIG. 13—*Ship A purging tank No. 1 starboard*

Fig. 14 shows a typical mixing curve when hydrocarbons were removed by inert gas admitted through the cargo suction lines. It will be observed that the process is much slower, although the atmosphere is more uniform. The final variations in hydrocarbon level are not significant when inert gas is present, as no concentration would dilute through the flammable range if air was admitted. If, however, air had been used to produce a "lean" atmosphere, some of the hydrocarbon concentrations would have been in the flammable range when those in the vent outlets were probably not.

It was observed on several occasions that gas layering appeared to be preserved during the ventilating or purging process. If these layers were left undisturbed for a few hours, uniform atmospheres returned.

Fig. 15, which is typical of many, shows that during the initial inerting of a large tank when using the purge pipe to exhaust the gases, a small volume exists near the top of the tank with higher oxygen concentrations than at other levels. Long before purging is complete, the gas concentrations become nearly uniform. The purge pipe readings follow closely the simple mixing theory and are in no sense misleading when the exhausted gases are within one per cent of that being supplied, which our instruction book indicates is the time to stop purging.

The tests on these large crude oil vessels confirmed that the methods of operating and monitoring were valid. Purging with

TABLE VI—PURGING AND VENTILATING CLEAN AND DIRTY TANKS

Ship	A		B	
Direction of gas flow within the tank	Down		Up	
State of tanks	Clean	Dirty	Clean	Dirty
Operation	Purging		Purging	
Incoming gas	Flue gas	Flue gas	Flue gas	Flue gas
Tank contents	Air	Flue gas + hydrocarbons	Air	Flue gas + hydrocarbons
Dominant process	Dilution	Displacement	Displacement	Dilution
Operation	Ventilating		Ventilating	
Incoming gas	Air	Air	Air	Air
Tank contents	Flue gas	Flue gas + hydrocarbons	Flue gas	Flue gas + hydrocarbons
Dominant process	Displacement	Displacement	Dilution	Dilution

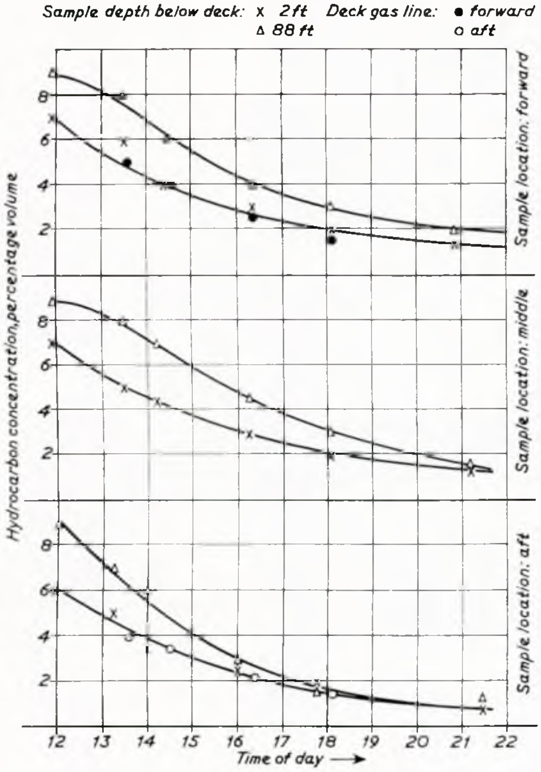


FIG. 14— *Ship B purging tank No. 3 centre*

inert gas before tank washing commenced, gave tank atmospheres which could not be subsequently diluted with air to form flammable mixtures, when men were in the vicinity.

In comparison with the "lean-air" or "over-rich" methods the method of inerting as advocated in this paper provides a third dimension of safety in that the gas atmospheres are deficient in oxygen, irrespective of the hydrocarbon gas concentration. The hydrocarbon concentration may be reduced easily to acceptable values by purging with inert gas before venting with fresh air, thus avoiding the dilemma of other methods. "Gas pockets" may occur after venting in a non-inerted vessel and these may be flammable air/hydrocarbon mixtures. If "gas pockets" occurred on an inerted vessel, they are unlikely to be flammable as they were originally composed of inert gas/hydrocarbon mixtures.

The inert method is applicable throughout the whole cycle of tanker operations and requires a gross element of mal-operation to reduce its effectiveness as a *safety measure* on a modern vessel.

4. THE EFFECT OF INERT GAS ON THE CORROSION OF CRUDE OIL VESSELS

4.1 *Laboratory Tests*

Laboratory tests were carried out on a limited scale in 1960 and 1961. Small test coupons, weighing about 100 grams, were tested in conditions likely to occur in cargo tanks using an atmosphere containing 9 per cent oxygen.

The tests carried out in 1961 were initiated to determine the effects of sulphur dioxide on the rates of corrosion. Although the concentration of SO_2 was varied from 0 per cent to 0·18 per cent, the latter figure representing unwashed flue gas from 3·5 per cent sulphur fuel, no significant effect of SO_2 on the corrosion rate was found.

However, the presence of sulphur dioxide caused a tenacious black deposit on dry surfaces. The possible effects of absorption of SO_2 by soot deposits lying in the inert gas delivery main was not investigated. Such deposits could remain undisturbed for long periods, continuing to absorb sulphur dioxide until highly acidic.

It was for this latter reason that the high standard of better than 90 per cent SO_2 removal was specified for the scrubbing tower. It is also one reason why cargo tank corrosion rates were not assessed by measuring weight losses of test coupons placed in the inert gas delivery line.

The laboratory tests were carried out over a few weeks, and in view of the very small weight losses (0·067 grams to 0·119 grams) the results were rightly treated with caution. The predicted corrosion rates of 0·014 in/year and 0·005 in/year in air and inert gas respectively were later shown to be surprisingly good estimates.

4.2 *Test Plate Results*

Test plates were fitted to five vessels in positions indicated in Fig. 16. The test plates were mounted on racks and were cut from the same sheet of mild steel shipbuilding plate. Each test plate measured 12 in × 12 in × 0·4 in thick, and weighed about 16 lb 3 oz.

The ships selected represented steelwork in various states of corrosion. The oldest ships, *British Skill* (inerted) and *British Talent* (non-inerted) had just completed their second survey. *British Prestige* was a new vessel, and to obtain a more direct comparison six tanks (Nos 8, 9 and 10 port wing and port centre) were isolated from the inert gas supply. *British Victory* (non-inerted) was used to compare results obtained on her inerted sister ship, *British Sovereign*.

The raw data obtained from the test plate trials is given in Table 7. This data includes such factors as empty tank time, clean and dirty ballast days, etc. The tests extended over a five-year period, and Table 7 shows the average weight loss per annum of the test plates on each vessel at the upper, middle and lower levels of the tanks.

The results were statistically analysed in the hope that regression equations could be found that would account for variations in empty tank time, clean ballast days, etc. As the amount of data available was strictly limited the analysis was not very successful, but the empty tank time emerged as an important parameter.

It was shown, as was to be expected, that the corrosion was greatest in the ullage space. A significant effect of inert gas was also observed on the tie beams, but no reduction in the already low corrosion rates could be detected on the tank bottoms. (See Table 7.)

4.3 *Ultrasonic Measurements*

Over 1600 measurements of thickness were taken annually on each of the five vessels using ultrasonic machines. The measurements were made about 3 in below the deck on certain transverses, longitudinals and girders. Surfaces were descaled by chipping hammer before measuring. It is considered that any extraneous influence on the results caused by the surface preparation of the measuring points would have been common to all the vessels.

The tests extended over a six-year period during which a wealth of confusing information was collected. It was found that operator, machine errors and the effect of surface roughness gave a total error about equal to the annual corrosion rate. The introduction of new ultrasonic machines made only a marginal improvement in the accuracy obtained, and when results were compared between the new machine and the old, the basic differences in calibrations added to the confusion. Ref. 6 records the studies made to assess the machine and other errors, and their influence on the derived regression equations. It is sufficient to say here that, although many variables were tested, the major indication emerging from the statistical approach was that empty tank time in association with inert gas was a major factor. The reduction in corrosion by using inert gas was expressed as about 0·001 in per 30 days empty.

In view of the large numbers of readings taken however it is fair to compare the mean values of vessels fitted with inert gas

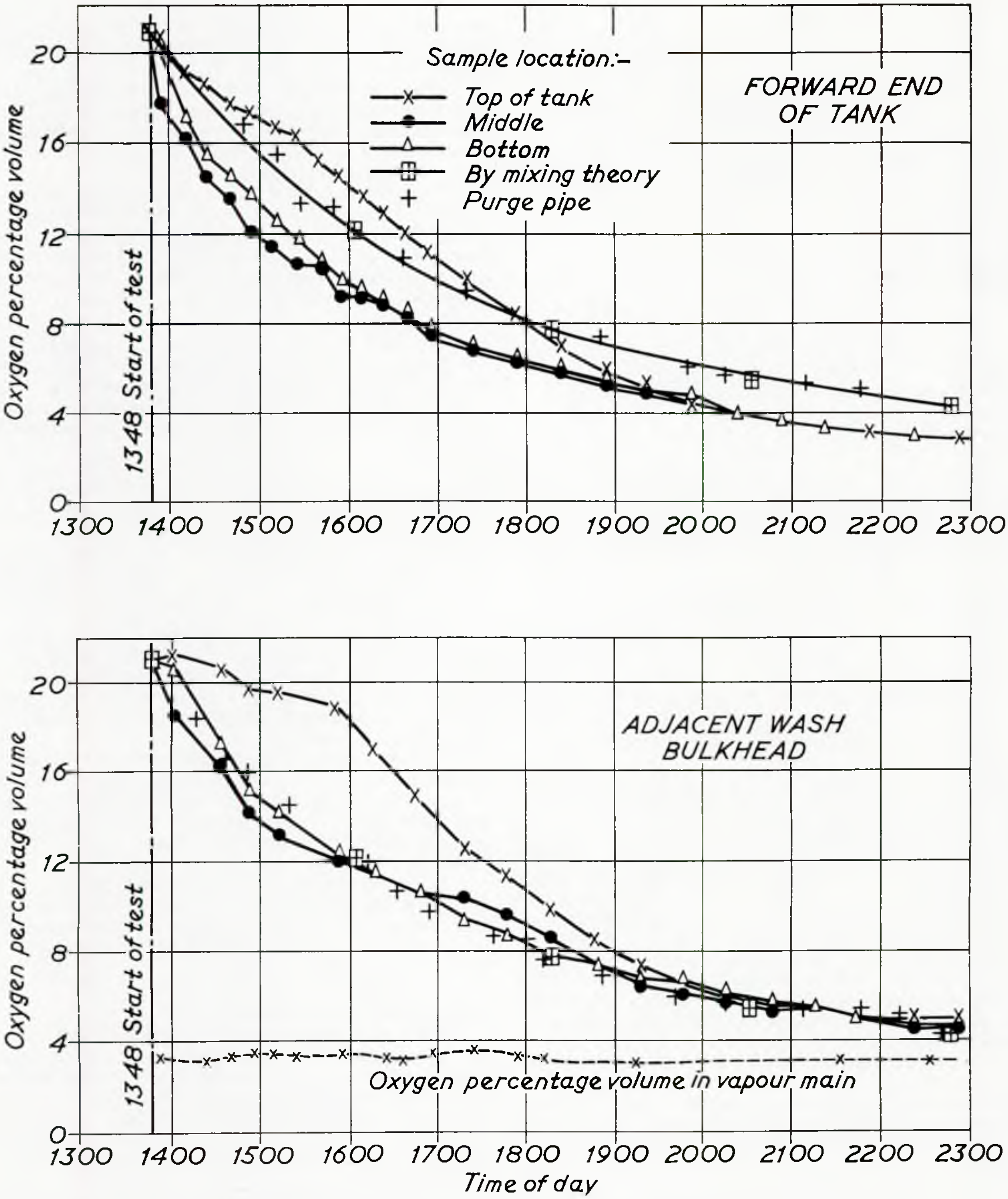


FIG. 15—*Ship A test to determine distribution of 0_2 during initial inerting 24 March 1970*

with those which are not. Table 8 records the mean thickness loss determined from the ultrasonic measurements, which refer only to the ullage spaces.

4.4 *Overall Presentation of Corrosion Results*

It was considered that the simplest way to appreciate the effects of inert gas was to examine the mean values of the corrosion rates determined by the various methods. Provided then the results are regarded as indicating the average trend and not applied to individual tanks, the effect of inert gas was to reduce corrosion rates in the ullage space by values varying from 28½ per cent on *British Skill* to 58 per cent on *British Sovereign.*

The problem remains to explain why the results should be so much better on one ship than another. It was known that the inert gas system on the *British Skill*, being the prototype, suffered more defects than later systems. Accordingly, Table 9 was prepared. This table shows the average oxygen content of each vessel during the test period, and indicates the corrosion rate in inches per annum (both sides). Results on Table 9 have been plotted in Fig. 17, which suggests that the corrosion rate is dependent on the oxygen content. Later systems have proved more reliable than those fitted to the three vessels considered here, and the average oxygen content of more modern vessels would be significantly less.

For vessels engaged on world-wide trading, and fitted with the latest version of the inert gas system, the average corrosion rate in the ullage space would be about 0·005 in per annum compared with a non-inerted vessel having figures of about

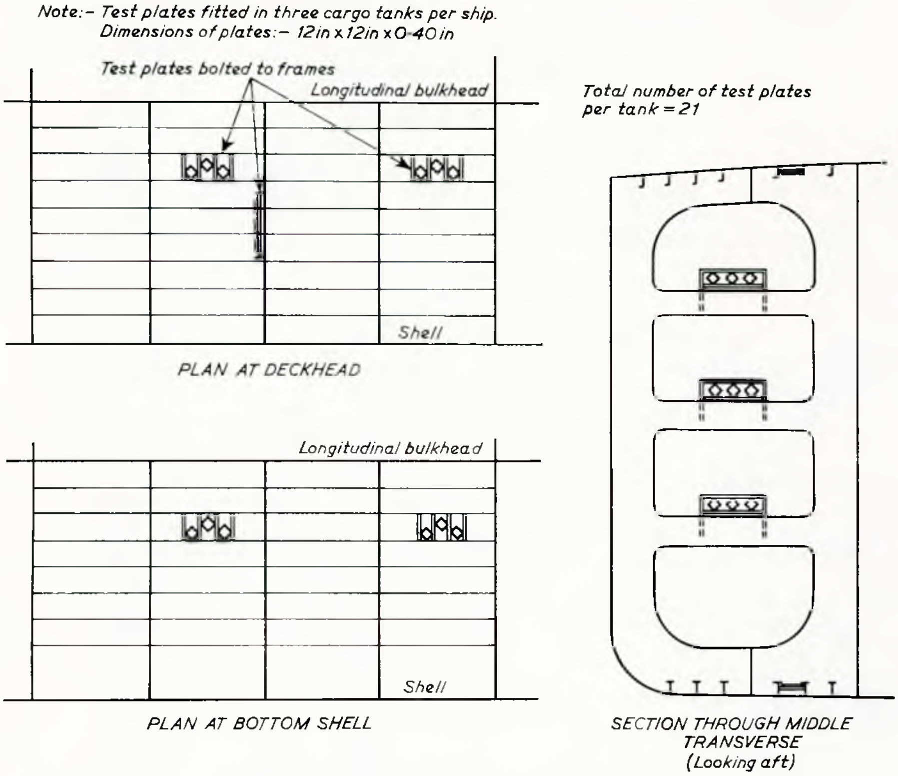


FIG. 16—*Positions of test plates*

TABLE VII—SUMMARY OF RAW DATA

	British Skill	*British Sovereign*	*British Prestige*	*British Talent*	*British Victory*	All ships combined
Percentage of test plates:						
Cathodic protection	33	30	88	66	50	60
Inert-gas protection	100	100	67	0	0	53
Days between weighings (range)*	365–1,181	368–1,171	313–1,122	313–1,142	381–1,218	313–1,218
Days/annum test plates in tanks which were:						
Empty	167	132	128	146	129	139
Clean ballast	16	26	35	35	44	32
Dirty ballast	17	21	32	14	15	21
Occasions in clean ballast, per annum†	0·8	3·6	4·9	4·1	3·2	3·5
	Deckheads					
Number of plates	30	32	48	28	18	156
Mean loss, oz/annum	5·4	2·7	3·7	10·6	10·2	5·8
Range	1·2 to 9·7	0 to 5·2	0·7 to 6·7	3·9 to 17·9	4·3 to 21·2	0·0 to 21·2
	Tie beams					
Number of plates	45	54	72	53	43	278
Mean loss, oz/annum	3·5	2·8	3·4	4·9	4·0	3·7
Range	0·8 to 9·2	−0·2 to 6·9	0·3 to 12·5	0·3 to 11·9	0·4 to 12·2	−0·2 to 12·5
	Bottom shell					
Number of plates	30	36	48	30	36	180
Mean loss, oz/annum	4·1	3·2	5·2	3·7	4·6	4·3
Range	0·2 to 7·3	0·7 to 9·9	−3·5 to 13·5	−3·1 to 8·7	0·4 to 10·0	−3·5 to 13·5

* The second batch of test plates (years 4 and 5) have been included as supplementary readings for years 1 and 2.
† The figures quoted as per annum have been derived from averaging out the data for the five years and correcting for 365 days.

TABLE VIII—SUMMARY OF MEAN THICKNESS LOSS AND RELATED VARIABLES

	British Victory (non-inert)	*British Talent* (non-inert)	*British Sovereign* (inert)	*British Skill* (inert)	*British Prestige* (part inert)
Mean thickness loss per annum, in	0·012	0·014	0·005	0·010	0·005
Mean number of days/annum in dirty ballast	18·2	15·8	17·2	14·8	21·9
Mean number of days/annum in clean ballast	35·2	39·4	39·4	40·9	39·4
Mean number of occasions/annum in clean ballast	4·7	5·2	4·7	4·5	5·0

TABLE IX—DECKHEAD CORROSION RATES AND OXYGEN LEVELS

	British Skill	*British Sovereign*	*British Prestige*	*British Talent*	*British Victory*
Mean thickness loss per annum by ultrasonic measurement, in (Table 8)	0·010	0·005	0·005	0·014	0·012
Loss by test-plate method (Table 7):					
Weight loss, oz/annum	5·4	2·7	3·7	10·6	10·2
Equivalent thickness loss, in	0·0082	0·0042	0·0057	0·0162	0·0156
Laboratory test prediction	Inert (9 per cent oxygen) 0·005 in			Non-inert 0·014 in	
Average oxygen content in tanks while empty, percentage. Annual repair period:					
Included	12·4	8·2	9·3	21	21
Excluded	9·8	5·4	7·4	21	21
Average oxygen content in test-plate tanks only, percentage. Annual repair period:					
Included	12·2	8·2	10·3	21	21
Excluded	10·1	5·4	8·0	21	21

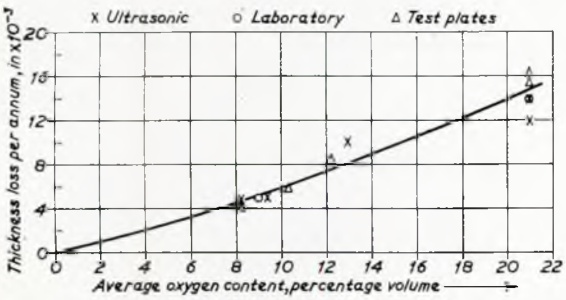


FIG. 17—*Relationship between average oxygen content and mean corrosion rate in ullage space*

0·014 in per annum. These corrosion rates refer to the loss of thickness in a structural member at a point about 3 in below the deck. They must not be used for points lower than this as the corrosion rate falls rapidly in the first foot of depth.

The effect on steelwork renewals is difficult to estimate and will depend on the initial thickness of the plate. Renewals at the first special survey are almost unknown on crude oil carriers. Considerable renewals, of bulkhead tops, deck transverses and longitudinals may occur on non-inerted crude oil vessels at their second survey. A corrosion rate of 0·014 in per annum would result in renewals of these members in the ninth year of service, but material over 0·93 in is unlikely to be renewed within a 20-year life. At an inerted corrosion rate of 0·005 in per annum, no renewals of structural members of the usual thicknesses are foreseen, but if the corrosion rate increased locally to 0·0075 in per annum material under 0·50 in would be suspect at the last survey.

The saving in steelwork renewals would be a substantial commercial benefit, but modern practice is to prevent these by coating the vulnerable areas such as the deck head at much lower cost. The savings in capital cost for the deletion of these coatings in all cargo tanks is comparable with the cost of fitting an inert gas system, including the provision of the delivery line on deck and purge pipes within the tanks.

4.5 *Reduction in Scale on Inerted Vessels*

During the period of corrosion assessment, reports came in from the ships that the scale was more adherent and harder on the inerted ships compared with the non-inerted ships. It was also remarked that there was less necessity to lift scale or sludge from the inerted vessels. Accordingly an examination has been made of the records for the 50 000 ton class of vessels. The first four 50 000 ton vessels were not inerted originally but the remainder were. (The back-fitting of the first four vessels is now being undertaken.) Table 10 given below shows the quantity of scale lifted on each vessel.

It will be seen that the average amount of scale lifted on the inerted vessels is about 25 per cent of that lifted per annum on the non-inerted vessels. This reduction corresponds roughly with their expected relative corrosion rates, but in view of the partial painting of the deck heads on the non-inerted vessels the results are better than might be anticipated. However, it is known that the inert gas systems have worked particularly well on this class, figures of about three per cent oxygen having been maintained over long periods.

4.6 *Effect of Inert Gas on Pitting Corrosion*

Major pitting damage occurs in tanks that are ballasted after tank washing. On *British Prestige*, the cathodic protection was omitted from certain tanks to discover whether inert gas was effective against pitting. Very severe pitting occurred on

TABLE X

Vessel	Period, years	Tons scale lifted Total	Average/year	Remarks
British Queen	10	477	47·7	Deck heads coated after 6 years
British Hussar	7	155	22·1	Vessels' deck heads coated over ½ area from new
British Bombardier	7	107	15·3	
British Cavalier	7	150	21·4	
		Average scale lifted per year = 28·7		All 4 vessels non-inerted
British Grenadier	6	34	5·7	No coatings applied
British Lancer	6	55	9·2	
British Guardsman	6	52	8·7	
British Dragoon	6	48	8·0	
British Diplomat	6	27	4·5	
		Average scale lifted per year = 7·2		All 5 vessels inerted

horizontal surfaces in the tank from which the zinc anodes had been omitted, and as might be anticipated, it was concluded that the inert gas does not have the opportunity to prevent this type of corrosion, which occurs when the tank is ballasted. Consequently it is essential that anodes be fitted in tanks that are regularly filled with clean ballast after tank washing. (The pitting in the unprotected inerted tank was estimated to have corroded four times as much steel as in the cathodically protected inerted tank.)

5. THE EFFECT OF THE PRESSURE OF INERT GAS ON DISCHARGING CARGO

As the cargo is discharged, the resultant void is filled with gas supplied from the vapour main. The pressure losses from the mast outlet to an individual tank on a non-inerted vessel are of the order of 0·5 lb/in² g. When the gas is supplied from a fan with an over-pressure of between 1·0 and 1·5 lb/in² g, the pressure over the cargo is therefore between 1·5 and 2·0 lb/in² g more than the normal case.

If the gas delivered under pressure were air, the probability of explosive mixtures occurring would be increased and the corrosion benefit would be reversed. Furthermore, the addition of scrubbing tower and engine room piping would be all that was required to make up an inert gas system, assuming, of course, that the vapour main was already provided.

Nevertheless, one of the benefits of fitting an inert gas system of the type described in this paper is an improvement in the rate of cargo discharge, especially during the stripping operation. It had been considered that this would be a small improvement as the discharge pressure of the pumps was usually about 125 lb/in² g. However, when the *British Skill* reduced her total discharge time from about 28 hours without inert gas, to about 20 hours after inert gas was fitted, this subject was re-examined.

It was quickly realised that the pressure provided by the inert gas was very significant in relation to the required net

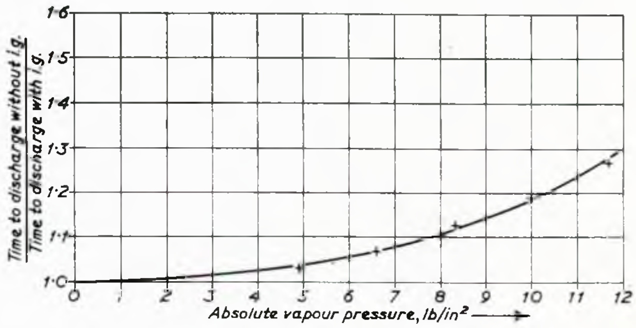


FIG. 18—*Effect of inert gas pressure on time to discharge*

positive *suction* pressure of the pump, which was of the order of 8 lb/in² g before the pumps cavitated at full flow. Other factors being equal then, the depth of oil in a tank would be about 3·5 ft to 4·5 ft less in an inerted vessel than in a non-inerted vessel before stripping commenced.

Fig. 18 results from theoretical calculations and shows that the reduction of cargo discharge time caused by the pressure of inert gas becomes more significant the higher the vapour pressure of the cargo.

It is worth recording that the reputation of the inerted vessels was such that the delivery of Uhm Said crude at Little Aden was preferred from inerted vessels, which would discharge this volatile crude completely. Other non-inerted, more modern vessels, had to give up the unequal task of stripping after nearly a week with still over 10 ft of oil in the tank bottoms and return to the Persian Gulf.

The inert gas systems designed by the authors' company now take maximum advantage of the pressure of the inert gas. Any saving in first cost obtained by rating the system to just match the cargo discharge condition without over-pressure, would be negligible in comparison with the value of the reduced cargo discharge period.

PART II—DESIGN CONSIDERATIONS, AND SERVICE EXPERIENCE

In this section of the paper, the design of the system and its components are considered in detail under the following headings:

6 System Capacity
7 Generation of Inert Gas
8 Scrubbing Tower and Demisters
9 Inert Gas Fan
10 Piping and Valves
11 Safeguards
12 Controls and Instrumentation

6. SYSTEM CAPACITY

The rated capacity of the system must at least equal the maximum cargo pumping rate, and also be related to the other various cycles of tanker operation. Due consideration must also be given to the size and weight of equipment, standardization and cost.

Specifically, systems are currently designed to provide:

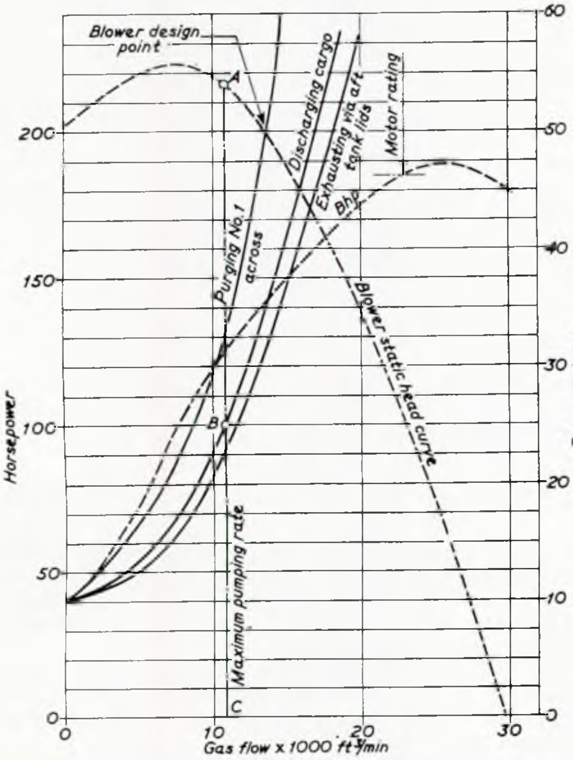
a) a capacity of about 1·33 times the maximum cargo pumping rate;

b) approximately 1 lb/in^2 g over-pressure on the cargo at the design cargo pump output;

c) a maximum of 1·5 lb/in^2 g over-pressure on the cargo under no-flow or low cargo pumping rates;

d) a rate of purging which does not delay significantly other operations.

A satisfactory purging rate normally results when requirements a), b) and c) have been achieved. Fig. 19 shows these design points on a typical pressure-capacity diagram.



Pressure above cargo at any given discharge rates = pressure delivered by fan—system resistance i.e. maximum cargo discharge rate
Pressure over cargo = AC - BC

FIG. 19—*Typical pressure—capacity diagram*

7. GENERATION OF INERT GAS

The main or auxiliary boilers are utilized for the generation of inert gases. Steamships have two equally sized water tube boilers, but the motor vessels fitted with inert gas systems have one water tube boiler, referred to as the auxiliary boiler, and one packaged smoke tube type. (The decision to change from Scotch boilers to water tube boilers was made independently of a decision to put inert gas on motor ships. However it is undoubtedly more difficult to obtain flue gas of low oxygen content with Scotch boilers, which have nevertheless been successfully used by other companies for this application.)

Present day combustion equipment operating at the normal evaporation design rate should provide ample boiler flue gas with oxygen contents of between two and four per cent. (See Table 11.)

7.1 *Steamships*

In earlier ships, such as *British Skill*, the combustion equipment required more attention than in more modern vessels.

TABLE XI—TYPICAL FLUE GAS COMPOSITIONS

Excess air percentage vol.	Total N_2 percentage vol.	CO_2 percentage vol.	O_2 vol.
0	85	15	0
10	84·4	14·5	2·1
20	83·8	12·0	4·2
25	83·5	11·3	5·3

With reasonable care, however, the oxygen content could be kept below five per cent during discharge of cargo. The oxygen level should not be reduced to the extent that heavy soot deposits occur. A typical relationship between oxygen content and solids burden in the flue gas from a water tube boiler under varying load is shown in Fig. 20. It will be seen that the quoted oxygen levels may be obtained with little risk of excessive solids.

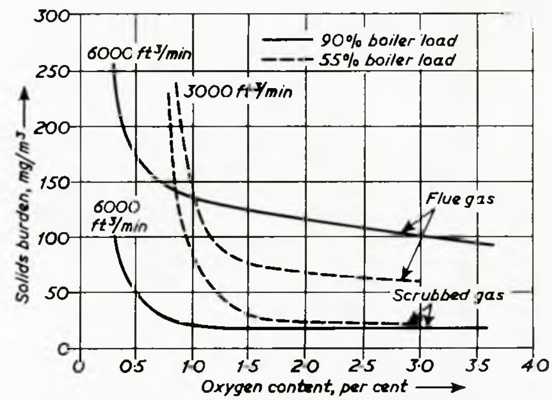


FIG. 20—*Relationship between flue gas/inert gas solids burden and oxygen content and boiler load*

Steam atomizing burners, with better turn-down characteristics, have improved the control of the oxygen level of the flue gas under low boiler load conditions, which had initially been a cause of less efficient combustion and low quality flue gas, especially at times when cargo pumping was restricted. In these circumstances, it is sometimes desirable to shut down one boiler, and particular attention must be given to flue gas quality. The need to maintain good combustion conditions in boilers at all times for inert gas brings its added reward.

The steam requirements for cargo pumping increase directly as deadweight, but the main engine power only increases slowly with increasing size of ship. The larger the steamship, therefore, the more the cargo pumping requirements relate to steaming power, and the easier it becomes to obtain high quality flue gas during discharge of cargo.

The boiler loading of a steamship ensures that purging with inert gas can commence soon after leaving a discharge berth in readiness for tank washing. Under abnormal conditions, such as long periods at "Dead Slow Ahead", the load on the boiler could be increased by operating one or two cargo pumps from sea to sea.

7.2 *Motor Vessels*

In motor vessels where the "auxiliary" boiler output is based on the demands of the turbo alternator and all the cargo pumps, flue gas of low oxygen content should be available throughout the discharge of cargo, the conditions being similar to those experienced on very large crude carriers. At sea, whether the electrical load is generated by a Diesel generator or from steam produced in a main engine waste heat recovery system, the boiler must be artificially loaded to obtain good quality inert gas before tank washing commences. This is achieved by operating one cargo pump, which will have been used for ballasting, on sea suction and discharge. Tank washing follows with one pump in operation, and sufficient high quality inert gas is available.

A packaged boiler is provided, which operates automatically at sea, to back up the waste heat recovery system, should, for example, a reduction in steam generation occur when the main engine is slowed down. Gases from this boiler can be conveniently used when restoring the pressure in the cargo tanks in the ballast and loaded condition. This boiler also provides a convenient method of producing adequate quality gas to maintain the tank pressure in a ship undergoing repairs in a drydock port in an inerted but not gas-free condition.

Because the volume of flue gas produced from this packaged boiler is less than the maximum capacity of the inert gas system, the flow must be restricted to avoid the dilution of the flue gas by fresh air drawn from the funnel top. Thus, in emergency, flue gas from the package boiler may be used for other operations in addition to topping up, provided a longer inerting period is accepted.

It should be emphasized that the care required to produce low oxygen flue gas should be no greater than that necessary for the control of combustion to achieve full economy. The few special requirements for inerted ships represent a negligible increase to the work load of the engine room staff. Hence, provided the ship is fitted with modern combustion and control systems, the generation of satisfactory flue gas by main or auxiliary boilers presents little, if any, problems in boiler operation. Maintenance should be reduced by the greater attention paid to combustion conditions.

8. SCRUBBING TOWER AND DEMISTER

The function of the scrubbing tower is to clean and cool the flue gas, and reduce the sulphur content.

By washing, or scrubbing the flue gas with sea water, a major proportion of the soot particles are removed, and the gases are cooled from the boiler uptake temperature to within 5°C of the sea temperature. The ratio of salt water to gas flow determines the percentage of sulphur dioxide removed, but there is an optimum quantity of sea water for a given design of scrubbing tower (Table 12).

As a result of laboratory experiments, it was decided to aim for 90 per cent removal of SO_2 and the maximum possible reduction in solids burden. In practice, the SO_2 removal is usually higher than 90 per cent and solids burden should not exceed 8 mg/m^3. No measurable quantities of sulphur trioxide will be present after scrubbing.

The water rates required by the various types of scrubbing tower to remove a given percentage of SO_2 do not vary greatly. Solids removal appears to be more closely linked with the pressure drop across the scrubbing tower. The selection of the scrubbing unit must, therefore, be related to the type of tanker, cargoes and combustion equipment.

8.1 *Bubble Cap Tray Scrubbing Towers* (see Fig. 21)

Bubble cap, tray scrubbing towers are extensively used in land practice especially in oil refineries, and for our first inerted ships it was decided to adopt this type of unit.

The flue gas enters the base of this type of tower through a submerged inlet pipe and flows upwards, bubbling through each capped tray. These trays are spaced approximately two feet apart and are flooded to a controlled depth with water. The scrubbed gases leave at the top through demisters and enter into the fan suction piping.

The sea water enters at the top tray and after flowing across, falls to the next tray and so on until it reaches the base from whence it drains overboard.

Originally all parts were manufactured from mild steel plate and the internals were coated with neoprene. Although neoprene proved to be successful on the shell, this was not so on the bubble caps. Fig. 25 shows the damage caused when the inlet pipe failed on the *British Skill*, which later led to the use of incorrodible materials in preference to coatings on the critical parts of the scrubbing tower.

In 1961, seven-tray scrubbing towers were installed in *British Skill* and *British Sovereign* (Fig. 21).

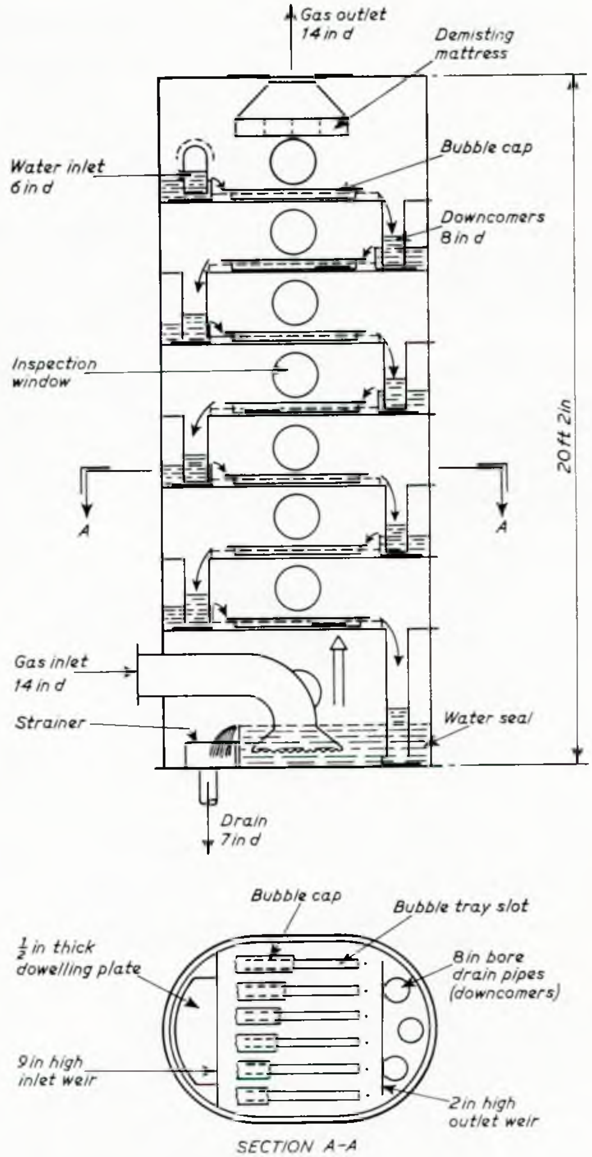


FIG. 21—*7-tray bubble cap type scrubbing tower as fitted to s.s.* British Skill *in March 1961 (3300 ft^3/min)*

The performance of the scrubbing tower in *British Sovereign* was measured in service and the results are shown in Table 12. It was deduced that the unit was over-efficient in sulphur removal and would operate satisfactorily with a reduced water throughput. Troubles were experienced with the drowning of the filters, and in 1962 the water supply was removed from the top two trays. This modification increased the disentrainment distance for water droplets before the demister, and reduced the total pressure drop across the scrubber without any significant change in the composition of the inert gas. The reduction of water carry-over had a beneficial effect on the maintenance of the fans and adjacent valves.

On later vessels, the number of trays were reduced. The results of the change on performance can be seen by comparing the test runs in Table 12. The total pressure drop across the unit at full flow is the total of the static pressures in the trays and seal plus losses depending upon the velocity head.

8.2 *Scrubbing Tower for Product Carriers*

Bubble cap towers were designed up to 6500 ft^3/min, but no significant technical developments were made until a new design was required for the product carriers. Service experience had

TABLE XII

	British Sovereign test runs 1	2	3	*British Prestige* test runs 1	2	*British Grenadier* test runs 1	2	3
Number of trays		7		3			3	
Gas flow standard f³/min	2430	2042	2042	1361	1406	4500	4500	4500
S.W. flow ton/hr	97	96	65	103	113	158	110	67
S.W. temp. °F	63	63	63	66	69	44	44	44
S.W. pH value	7·9	7·9	7·9	—	—	7·7	7·7	7·7
Scrubber inlet Sulphur dioxide ppm	2400	2220	2470	1200	1130	1620	1590	1680
Scrubber outlet Sulphur dioxide ppm	10	9	9	15	23	60·2	40	88
S.W. pH value	2·7	2·7	2·7	—	—	2·4	2·4	2·4
SO_2 removal percentage	99·6	99·6	99·6	98·8	97·9	96·3	97·5	94·8
Static pressure drop		20 in		12 in			12 in	

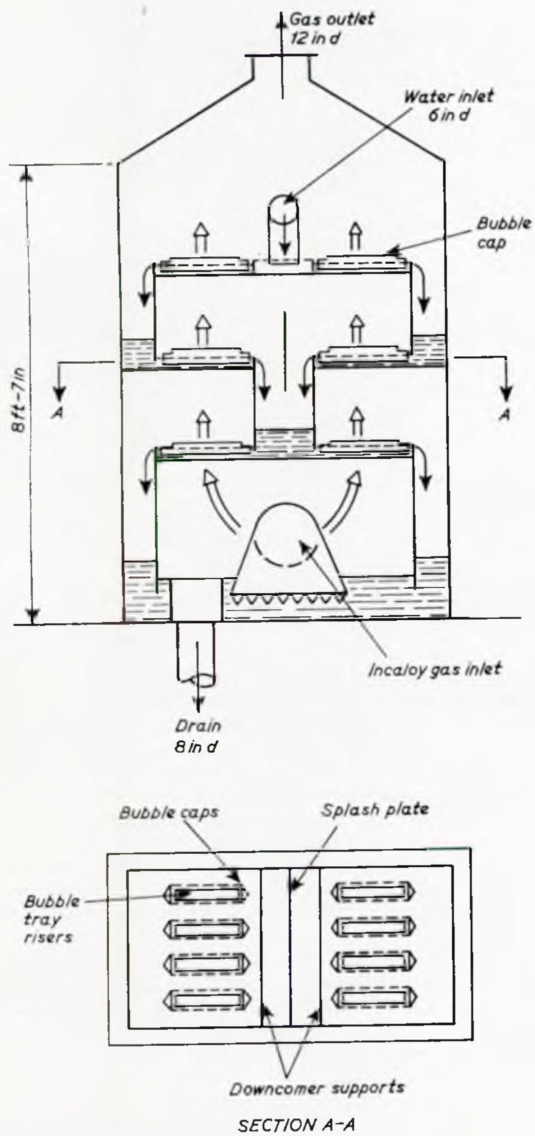


FIG. 22—*Product carrier scrubbing tower*

shown that a cleaner gas was possible with a bubble cap tower, and this type was considered more suitable for a product carrier.

A three-tray unit was designed for the 24 000 ton product ships. This was rectangular in shape and coated internally with neoprene. Material modifications included ni-resist cast iron trays and bubble caps, and Incaloy gas inlet pipe. Water flowed from the two sides to the centre, and vice versa, on each tray, and so on into the base and overboard.

The rated capacity of this tower was 3000 ft³/min at 60°F. The gas inlet temperature was 600°F, and the total pressure drop at full gas flow was designed to be 25 in w.g. when the scrubbing water rate was 120 ton/hr (Fig. 22).

The bubble caps are fitted in a fore and aft direction, as the rolling of a ship could vary the water level on the trays, thus allowing partially scrubbed gas to pass.

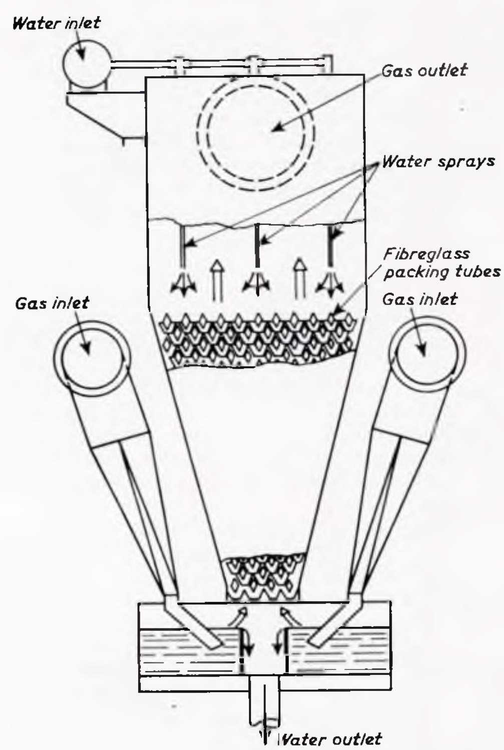


FIG. 23—*Packed spray type scrubber*

8.3 *Packed Spray Type Scrubber*

Following the satisfactory testing of a prototype, one of the licensees designed a light packed tower which could handle high throughputs at lower pressure drops than the bubble cap type. It was produced as a packaged unit, comprising demister, fans, controls and valves (Fig. 23).

The gas enters through submerged inlet pipes in the base, and passes upwards through the rhomboid shaped packing and demisters into the fan inlet. Sea water is directed downwards from the top section of the tower by six to eight equally spaced sprayers. The water drains through the packing, into the base and overboard.

The steel casing is coated with resin bonded glass fibre scrim and the packing is made of glass fibre slats. These have proved to be very successful anti-corrosion measures. Units of this type have been installed in several large crude vessels, and have been made in sizes varying from 4500 to 15 000 ft^3/min. Other details are given in Table 13.

This type of scrubbing tower meets specified standards of SO_2 and solids removal, but the low pressure drop is not achieved without some increase in the opacity of the scrubbed gases.

8.4 *Impingement and Agglomerating Scrubbing Towers* (See Fig. 24)

Scrubbing towers of this type were installed in two 68 000 ton tankers in 1965.

These units consist of a rectangular shell in several horizontal sections. The flue gas enters the bottom section through a submerged inlet pipe and is then wetted by sprayers fitted in that section. The gas then flows upwards through an agglomerating slot plate, three impingement plates and a demister before entering the fan suction.

Sea water is fed to the top impingement tray and is then transferred down through each stage until it finally drains into the bottom section and overboard.

The whole of the steel shell interior is heavily coated with neoprene. Incorrodible materials are used for the agglomerating and impingement plates and the gas inlet pipe.

It should be mentioned that venturi scrubbing towers, used by our French company, and other types have proved adequate for the purpose intended. Venturi scrubbing towers can some-

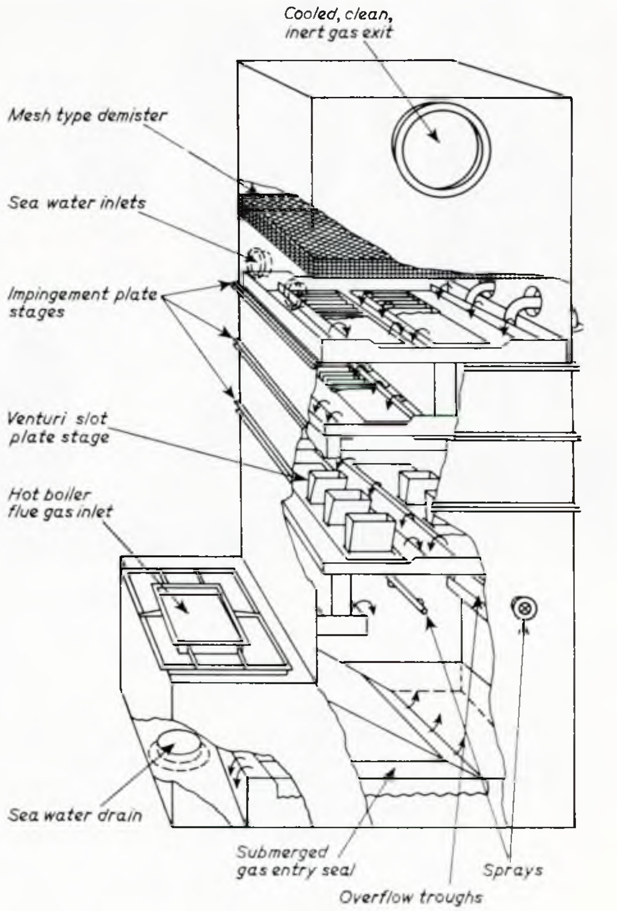


FIG. 24—*Impingement and agglomerating scrubbing tower*

TABLE XIII—CHARACTERISTICS OF SYSTEMS FITTED

Dwt $\times 10^{-3}$	30	45	55	68	24	111	215
Fan capacity—m^3/hr $\times 10^{-3}$	5·9	5·9	7·6	7·6	5·1	11·0	23·0
Volume of largest tanks—m$^3 \times 10^{-3}$	2·00	1·77	3·17	10·03	1·57	13·41	27·53
Total volume of tanks—m$^3 \times 10^{-3}$	38·02	51·61	63·22	83·05	33·31	138	266·18
Time for one air change—min (for largest tank)	20·3	18	25	79	18·5	73	72
Pumping rate (disch.)—m^3/hr $\times 10^{-3}$	2·38	3·28	4·83	5·78	3·91	8·96	18·8
Fan static pressure—mm W.G.	1600	1220	1422	1550	1600	1220	1270
Fan load (kW) purging	43	30	48	48	38	56	132
Scrubber water supply—tons/hr	100	100	100	100	110	170	350
Scrubber water pump load —kW	15	15	15	18	16	34	65
Type of scrubber	Bubble cap	Bubble cap	Bubble cap	Impgmnt. and agglom.	Bubble cap	Packed tower	Packed tower

FIG. 25—*Damage to gas scrubber on s.s.* British Skill *when inlet pipe failed*

times occupy less space than other types and SO_2 removal is as high as 99·7 per cent.

In concluding this section, it should be said that total removal of solids and SO_2 can only be achieved by the use of electrostatic precipitation and the use of soda injection to the washing water. Our experience dictates that these are unnecessary complications on crude oil vessels or product carriers, although they may well have application when special chemicals are carried.

9. INERT GAS FANS

It was decided from the outset to install constant speed electric motor driven, single stage fans having backward curved blades, in the BP system. It is thus possible to match the total system resistance with the fan pressure/volume characteristics in such a manner that the system would be self-regulating from no flow to full flow with convenient pressure levels existing during most tanker operations. (See Fig. 19 and Table 13.)

The safeguards associated with positive displacement blowers against the build up of excessive pressures are not required.

If additional generating capacity were necessary, the relative merits of electric or turbine drive would require careful consideration. Indeed, many owners have chosen turbine drive in preference to electric motors.

The vessels chosen for the prototype installations had sufficient generating capacity, and because of the resulting performance and ease of operation, constant speed motors have been used ever since.

To ensure maximum availability, two 100 per cent capacity fans are normally installed.

In order to reduce the electrical sea load, some of the 215 000 dwt vessels have been fitted with a smaller standby fan, which is suitable for use during the ballasting and tank cleaning operations. The smaller fan absorbs about 50 per cent of the power of the larger unit, but it can deliver up to 90 per cent of the quantity required for cargo discharge in an emergency. A reduced rate must be accepted to avoid negative pressures above the cargo. For this latter reason and for complete interchangeability, two 100 per cent fans are preferred.

Fan capacity is determined in relation to the designed cargo pumping and required purging rates. The required fan head is dependent on the following factors:

a) choice of scrubbing tower and demister;
b) selection of pipe bore in machinery space;
c) selection of pipe bores in deck distribution system;
d) an allowance of 27 in w.g. to 40 in w.g. over-pressure during cargo discharge.

a) The choice of scrubbing tower can make a difference to the total system resistance of up to 15 in w.g. at full gas flow.

b) The selection of pipe bores in the machinery spaces is made by balancing the cost of valves, piping and availability of space against resistance to gas flow. The piping between uptakes and scrubbing tower must allow for hot gas volumes well in excess of the design flow quoted at normal pressure and temperature at 60°F. It is therefore desirable that the scrubbing tower should be positioned as close to the boiler uptake as possible.

c) If the pressure drop along the deck distribution main is too great during maximum flow conditions, the pressure on the after tanks may cause relief valves to lift or the liquid seal to be displaced. A practical design figure of about 10 to 12 in w.g. has been found suitable under full flow conditions.

The diameter of the inert gas delivery main for large tankers with single mast outlets would be similar to the diameter of a vapour main on a non-inerted ship equipped for closed loading operations. Many tankers are fitted with large bulkhead valves, which are used to transfer cargo from one tank to another. A full tank could be levelled accidentally, into an adjacent empty tank, and this possibility requires the diameter of the gas lines to be increased to prevent a heavy suction pressure developing in the full tank.

On other vessels, where the tanks are vented in separate groups with an outlet for each group, the vapour main diameter would be inadequate, and a larger or an additional line in parallel would be necessary to limit the pressure drop to an acceptable value.

9.1 *Fan and Motor*

The fan characteristics are selected so that each fan will operate at the designed output at a point slightly past the peak of its characteristic curve. The rated output corresponds to that required for purging the foremost tanks across the ship which is normally the most onerous duty. Following a succession of motor burnouts, "non-over loading" fan/motor combinations are now required.

The motor rating should not be less than the power absorbed when the system resistance is at a minimum, which occurs if the inert gas is allowed to exhaust freely to atmosphere from the aftermost tank hatches. The above points are illustrated in Fig. 19.

9.2 *Construction and Materials*

In the light of service experience, many changes have taken place in the specification of the mechanical details of the inert gas fans.

The earlier fans were simply constructed, and the coated steel impellers were overhung on an extension of the motor shaft with a single gland on the discharge side.

Bearing life was short and, due to the construction, replacement of motor bearings was slow and arduous.

The bearing failures were usually attributed to either the unbalancing of the impeller by erosion from excessive water entrainment, or brinelling caused by structure borne vibration whilst the motors were stopped.

Although many coatings were tried, none were completely successful. Impellers of aluminium bronze have overcome the erosion problem, and are now specified.

In current installations, when ball or roller bearings are fitted, resilient mountings are provided together with flexible bellows pieces on each side of the fan. Alternatively, sleeve bearings may be fitted, and resilient mountings are not then recommended.

Separate bearings are now required for the fan. A bearing may be fitted on each side of the impeller, which requires two glands, or alternatively, two bearings should be positioned on the drive side of the impeller. A flexible coupling between the fan and motor shafts is specified.

Adequate drains with water seals are provided in the fan

TABLE XIV—DETAILS OF THE COMPONENTS ON A 215 000 DWT TANKER

	Type	Operation	Bore, mm	Material	Internal coating
Flue uptake valve	Butterfly (metal seal)	Pneumatic	700	Body: Cast iron. Blades: S.G. iron	
Flue uptake to scrubber piping			700	Steel	Galvanized
Scrubber drain piping			250	Glass reinforced plastic and polyester resin	Beyond water seal, polythene coated steel
Scrubber drain valve*	Screw down non-return	Manual	250	Body: Valve: Cr. steel	Neoprene or rubber
Scrubber to fans piping			2×700	Steel	Tar epoxy
Fan/isol. valves	Butterfly (rubber seal)	Manual	700	Blade: cast iron	Nylon
Fan control valve	Butterfly (rubber seal)	Pneumatic	700	Body: cast iron	Rubber lined
Fan to deck seal piping			700	Steel	Tar epoxy
Deck seal piping			Water inlet: 25 Discharge: 50	Discharge: Al-Brass/Kunifer 10/ plastic	
Deck main valve	Butterfly (rubber seal)	Hydraulic	700	Body: cast iron Blade: cast iron	Rubber lined Tar epoxy
Liquid p/v valve	Oil	Automatic		Steel	Tar epoxy
Deck distribution			Main 700 Branches 350/400	Steel	Tar epoxy
Purge pipes			350	Steel	
Mast riser valve	Butterfly	Hydraulic	700		Tar epoxy

* S.D.N.R. valve if below L.W.L.
Diaphragm valve if above L.W.L.

casing to prevent damage by any accumulation of water carried over from the scrubbing tower.

The fan/motor combination is the heart of the system, and as such should be built to the highest standards of reliability. High system reliability has been achieved principally by installing two fans. The period between major overhauls on each individual fan has been extended considerably by the measures described above, but the requirement that fan/motor combination should be non-overloading has prevented many potential motor failures.

10. PIPING AND VALVES

Table 14 gives the specification requirements for the pipes and valves for the systems installed on a 215 000 dwt vessel.

Originally the vapour mains were galvanized to protect them from corrosion. When inert gas was fitted, it was appreciated that soot would collect on the delivery line which could absorb SO_2, thus making the deposits in time highly acidic. Any places where condensed water vapour could lie in the line would be particularly vulnerable, for example at the after end of the gas line near the stop valve.

It is appropriate to mention that non-self-draining loops should be avoided. On *British Prestige*, for example, about 12 in w.g. unexpected pressure loss was only accounted for when it was discovered that the main gas line crossed the deck parallel to the camber. The trap so formed was provided with a drain and a quantity of acidic sooty water was drained off daily.

Since *British Prestige*, the inert gas delivery lines have been protected with coal tar epoxy paint after shot blasting. A smooth finish is specified to minimise the friction losses due to scale and also sooting of the line.

Following the failure of a stainless steel bellows expansion piece by pin holes in one year on *British Prestige*, rubber or neoprene bellows pieces have been used successfully: they are protected against fire by a steel box built round the rubber bellows.

Usually flanged steel pipe is used for the inert gas delivery line, but lighter spiral welded tube has been satisfactory for six years on one vessel. (Note: the supporting arrangements and scantlings of the pipes must be substantial enough to resist heavy weather.)

Originally, gate valves were used in the deck line. Recently butterfly valves have been fitted and are more convenient to use.

As the salt water passes through the scrubbing tower it becomes progressively more acidic until it leaves the base section with a pH value of 2 to 3. The tower material is protected against attack by coating or by the choice of materials which do not require coating. Originally mild steel effluent piping coated with a phenolic based resin was installed to conduct the water from the base of the tower to the ship side valve. Several breakdowns of the coating occurred resulting, very quickly afterwards, in perforations in the pipe wall. Eventually resin bonded fibreglass piping proved to be the most suitable material for this duty.

Rubber coated, diaphragm type ship side valves sited above the loaded water line are installed and have never been a source of trouble. (See Table 14.)

11. SAFEGUARDS

The safeguards referred to in this section are those associated with the system and not the relationship between the system and the safety of the ship.

Availability factor is increased in that two boilers are provided, and therefore two sources of gas. Two fans are installed.

Reversal of gas flow from the cargo tanks to the machinery spaces must be prevented. To prevent hydrocarbon tank gases returning to the machinery space, two non-return valves were fitted in earlier ships. These were in addition to the hand operated isolating valves.

It was found that all these valves could leak despite a maximum working pressure of only 2 lb/in² g. Maintenance of these valves was difficult and time consuming. An incident arising from the presence of gas in the machinery spaces, which fortunately was not serious, indicated a more positive device was needed.

A deck water seal was designed, and back fitted in all ships in service. The water seal was designed to withstand a reverse pressure of 70 in w.g. but only added about 6 in w.g. to the system resistance at full flow. The principle is illustrated in Fig. 26.

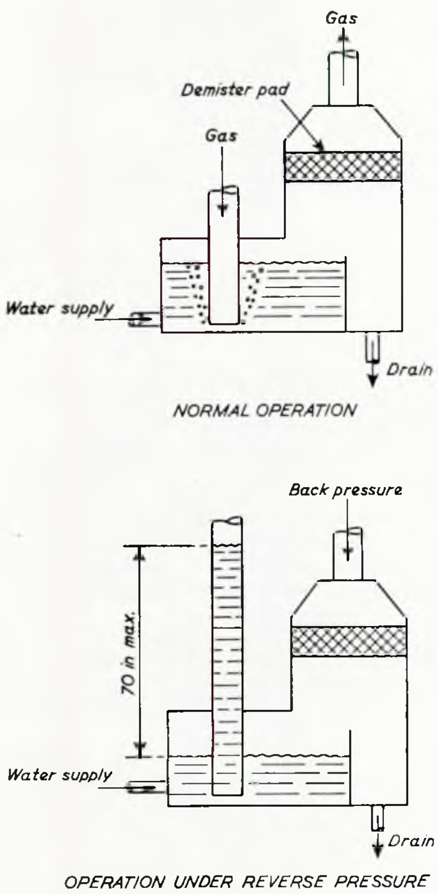


FIG. 26—*Deck water seal suitable for gas flows up to 4500 ft³/min*

At flows above 4500 ft³/min, it was found that both pressure drop and water carryover from the water seal became excessive. As a result, one of the licensees developed a deck water seal which operated dry at high flows; at low or no flow the inlet again becomes submerged without the use of mechanical devices. The pressure drop in the venturi section at high flows is used to lift the level of the water in that section which causes the water level at the gas inlet to fall. At low flows, the pressure drop in the venturi is insufficient to prevent the water returning to the gas inlet and the seal is thus re-established. This principle is illustrated in Fig. 27.

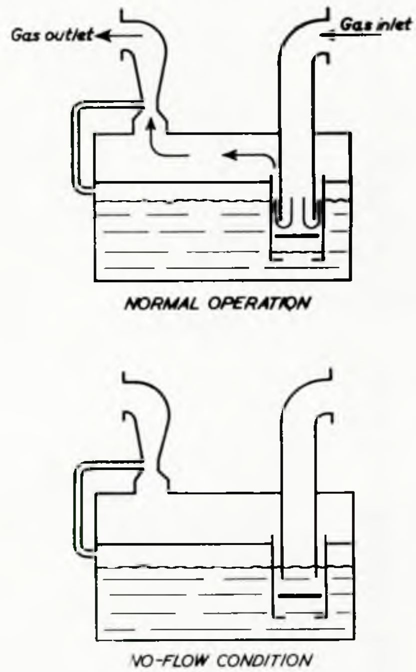


FIG. 27—*Deck water seal suitable for large gas flows*

A water seal has always been incorporated in the base of the various scrubbing towers to prevent reverse flow of gases to the boiler uptakes. This water seal is designed to withstand a reverse pressure of 60 in w.g.

High cargo tank pressure may occur in any tanker during the loaded passage due to the effect of temperature on the cargo. Conventional pressure/vacuum valves are provided to allow gases to escape to atmosphere when a positive pressure of 2 lb/in² or a negative pressure of 0·5 lb/in² g is reached. A liquid filled pressure/vacuum protection device is also fitted (see Part I and Fig. 6). It is a static piece of equipment requiring no maintenance, apart from a check of oil level.

Low cargo tank pressure alarm operates in the engine room and on the bridge if the pressure falls to 5 in w.g. The sensing point is immediately downstream of the deck water seal and isolating valves.

Scrubber flooding would occur if the overboard valve was left shut or the line choked. Under such conditions water would be admitted to the boiler uptakes. A simple overflow device is provided to give warning, and the inert gas line from boiler to scrubbing tower is arranged to allow sufficient time for action to be taken.

Low salt water supply to the scrubbing tower operates a switch to prevent a fan being started, and will stop a fan that is already operating. The pressure (or flow) switch is connected in the stop circuit of the fan motor starters and to audible and visual alarms.

This safeguard is necessary in order to prevent hot gases either damaging the coatings in the scrubbing tower or being discharged to the deck distribution system.

High gas temperature operates a switch set to operate at 140°F in the fan outlet and is connected to the motor stop circuit. The purpose of this device is to act as a backup device to the low water supply switch, and to stop a fan left running on no load if the temperature increased to the value stated.

Fan failure is indicated by a visual and audible alarm.

Seal water to the base of the scrubbing tower and the deck seal unit is supplied continuously to avoid the possibility of these drying out. Originally, this supply was provided from the main scrubbing tower water pump which was left running continuously. From Table 13 it can be seen that the electrical power consumption in the larger vessels is considerable. Additionally, the large constant flow of water through the tower caused a vacuum to develop which acted adversely on the deck water seal.

The present practice is to fit a small pump of approximately 30/50 gal/min to supply the sealing water to both the scrubbing tower and deck seal. This ensures a constant water supply when the inert gas system is shut down.

Gas sampling of O_2 or CO_2 can be used as a measure of the suitability of the flue gas as an inerting media as well as a guide to the efficiency of the boiler combustion equipment. Fixed systems in earlier ships were installed to measure CO_2. Since 1967 the measurement of O_2 has become a specified requirement.

Audible and visual alarms are provided which operate when the CO_2 falls to ten per cent or the O_2 rises to five per cent. These are connected via the analysing equipment points on the boiler uptakes. A sensing point from the inert gas fan discharge line confirms that the quality of gas leaving the fan is similar to that in the boiler uptakes. Any reduction in quality will indicate that air is being drawn into the system between the uptakes and fan inlet which is under suction pressure.

12. CONTROLS

It has been our policy to keep control equipment to a minimum, consistent with ease of operating the system. All controls in the engine room are centralized in the control room, but local start/stop buttons are also provided for the fans.

Boiler uptake valves should be shut when the inert gas system is not in operation. Remote power operation of the uptake valves from the soot blower panel with open/shut indication is provided. A notice is attached to the panel to indicate that the valve should be closed on the particular boiler before blowing tubes.

On some vessels, an interlock has been provided to prevent operation of the soot blowers when an uptake valve is open.

Scrubbing tower main water supply pumps can be started from the engine room control room. On ships which do not have the separate sealing water pump, the main pump is left running.

Fan suction and discharge isolating valves are manually operated, and are left open on the duty fan.

Pressure control valve is fitted in the discharge piping and is power operated. This valve can be remotely controlled from the pump room entrance or cargo control room. When pre-set, it will modulate and control the cargo tank pressure providing a flow of gas is taking place. This is useful during tank cleaning or sludge dipping operations, when a high pressure would be inconvenient.

This valve also closes when the fan is stopped and opens when the fan is started.

A hand operated gas outlet valve from the deck seal is opened only after the duty fan has been started and should be closed before the fan is stopped. On the very large crude tankers this valve is power operated.

Fan start-stop push buttons are placed in the engine control room console. The fans do not start or stop automatically except as indicated above, as this would add to the complexity. If the oxygen content were high, it is considered wiser to continue the supply of gas of inferior quality, as if the fan were stopped, the liquid seal would be displaced by the vacuum in the tanks, thus allowing fresh air to enter the system.

13. COSTS

The cost of an inert gas system in a new ship in 1971 could vary from approximately £50 000 for a 25 000 ton product carrier to about £150 000 for a 250 000 dwt carrier. These costs also include for the deck distribution system and cargo tank purge pipes, deck seal, valves, etc., in addition to the components, piping, controls, etc., in the engine room. The major cost item is the deck distribution system, which many conventional tankers have installed to facilitate closed loading, in which cases the true extra cost would be less.

The cost of the equipment from one of the recognized manufacturers does not vary greatly when compared with the size of the ship. On a large vessel the proportion of cost taken by the equipment in the engine room would be about 25 per cent of the total compared with 35 per cent on a product carrier.

Repair costs are being steadily reduced by the introduction of better materials, simplifications and cleaner gas. On the early system, high maintenance costs were due to replacements of fans and motors, bearings, and, in some cases, rebuilding of the whole or part of the scrubbing towers. Holes have appeared in purge pipes in tanks used for clean ballast after about seven years, but the use of coated steel or cast iron pipes is expected to prevent further renewals of this item. The main inert gas piping is expected to last the life of the ship.

On prototype systems, the annual repair costs were about 6 per cent of the initial cost, but this should reduce to 1 per cent on the latest vessels. These figures are not precise, but they are considered reasonable for estimating purposes.

14. CONCLUDING REMARKS

This paper has attempted to summarize ten years of development on the inert gas system. About 30 ships have been fitted with the inert gas system, including all crude oil ships whilst under construction for the authors' company since 1963, and all product carriers since 1968. No explosions have occurred in these inerted ships, whose operating experience covers 150 ship-years. However, even this is a small sample from which to predict the eventual reduction in explosion risk on inerted vessels.

It has been shown in Part I that a correctly operated system will prevent explosions, during all normal operations; this will be so even if oxygen concentrations above the minimum obtainable are experienced. However, ships' staffs should aim for optimum conditions as the lower the oxygen content achieved, the more the margin of safety will be improved and the greater will be the reduction in corrosion. In other words, the pursuit of optimum conditions, whilst these are not essential for effectiveness, helps to maintain the disciplined approach which is so essential where safety is involved; the prevention of corrosion provides a bonus incentive.

The emphasis on simplicity and reliability in design and operation appears in both parts of the paper. This has led to a reduction in the time taken by ships' staffs to comprehend fully the operation and maintenance of the system, which is so necessary at a time when crew changes are frequent. The office staff must also be fully familiar with the system, not only from the supervisory viewpoint, but to provide advice to ships' officers who may have little previous experience with inert gas. Nor of course does the matter end there. It is essential to provide training, comprehensive instruction manuals, and a follow-up system to ensure no maloperation is taking place. The normal safety regulations must be observed at all times whether or not an inert gas system is fitted.

It is often argued that the high cost of an inert gas system is difficult to justify on grounds of safety alone; the actual cost varies from ship to ship, and it will vary according to whether a centralized vapour main or individual stub vents were included in the non-inerted ship.

The value placed upon safety must always be a matter of judgement for the individual shipowner. In making that judgement, however, the substantial side benefits to offset the initial outlay should be taken into account, and these are now reiterated:

i) the reduction of corrosion has been found sufficient to render extensive tank coating unnecessary on crude oil vessels;

ii) there is a reduction of scale and sediment in comparison with that formed in uncoated, non-inerted ships;

iii) cargo discharge rates are improved, especially where oils of high vapour pressure are carried;
iv) engine repairs and hull painting can be done in inerted ships without tank cleaning or gas freeing, and this is being accepted by many repair port authorities.

The first of these items produces a substantial reduction in first coat, which would partially offset the cost of an inert gas system. The remaining items should result in a saving of time out of service.

In response to requests from all over the world for information on almost every aspect of inert gas, we have made this a long paper. Nevertheless, it is hoped that it will provoke further discussion to which the authors will be happy to reply. They write in their avowed belief that of all the means known to date to reduce the risk of tanker explosions, inert gas systems show the most promise and have the best chance, in the long term, of providing side benefits to offset the initial cost.

ACKNOWLEDGEMENTS

The authors wish to thank the directors of BP Tanker Co. Ltd. for permitting the publishing of this paper, and the Council of the British Ship Research Association for using certain diagrams and tables contained in Ref. 6. Certain other diagrams and advice have been provided by the licensees, to whom we are grateful. We also wish to acknowledge our debt to Sun Oil Co. Inc., and other companies in the U.S.A. for the information freely given during the early stages of our investigations. The authors are grateful for the assistance given to them by their colleagues in BP Tanker Co. Ltd. and at the BP Research Centre at Sunbury.

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Written Discussion

Mr. R. C. Kennett wrote that from an engineering point of view the paper was very informative.

He commented that he had accepted a ship in the inerted condition for floating repairs and if asked to, would dry dock it for inspection and painting.

Section 1.5 stated "... no repairs above the main cargo tanks". He preferred to put on his certificates "no repairs forward of the engine room bulkhead". Special conditions could enable further work to be carried out.

He tried to encourage the cleaning of the cargo pump room and associated lines before arrival; then if any repairs were necessary on the drive to the cargo pumps there was no possibility of gas entering the engine room.

Testing for oxygen in the inerted state was not absolutely straightforward as there were always considerable amounts of water vapour present. However, in his experience, the oxygen content had always been well below the accepted maximum.

Mr. R. M. Hosie, A.R.C.S.T., C.Eng., M.R.I.N.A. wrote that what seemed to be of paramount importance in forming a judgement on the merits of this system was to know how it would compare with the two other prospective methods of ullage space gas control outlined in section 3.4.2.5 in regard to the degree of safety provided on the one hand and to the complexity of design, operation and maintenance on the other. Both these methods, viz: "too lean" and "too rich", were capable, at least in principle, of being applied throughout the transport cycle of oil tankship operation with the object of minimizing the possibility of explosions from an internal source of ignition. Unfortunately, however, they had not been so applied in practice to date, and consequently this comparison was not possible. Certainly, the authors' comprehensive system, complete with regular monitoring and recording of tank atmosphere condition, could not be compared with the relatively simple application of the "too lean" system proposed (Ref. 1), and later adopted for tank cleaning only, by Logan (Ref. 9).

With regard to safety in the loaded condition the authors correctly maintained that in this particular situation, which, it had to be remembered, obtained for half the time spent at sea by a crude oil carrier, inert gas would fail to live up to the reputation of a cure-all. Indeed, the inert gas system would not seem to provide any greater, or lesser, degree of safety than a similar vessel without such a system. In both cases the atmosphere in the small ullage space would not support combustion from an internal source of ignition. In the event of a collision in which a tank ruptured, cargo spillage would induce dilution of the atmosphere with air. By taking the "before discharge" data provided in Table IV and plotting in the authors' flammability diagram for hypothetical mixtures, it could be seen from Fig. 28 that in

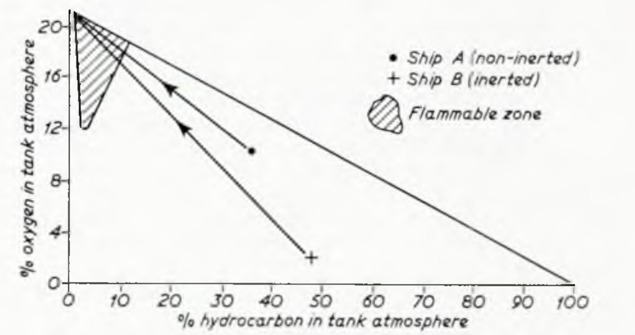

Fig. 28—*Dilution with air on collision in loaded condition*

both cases the ullage space atmosphere would pass through the flammable zone. In this situation a flammable hazard would certainly exist, for sources of ignition would be available from red hot metal in the rending of the ships' plates. There might not be an explosion since the relief area provided by the rent in the tank wall(s) would tend to minimize the pressure generated by the combustion of the tank atmosphere, but the volatile cargo would almost certainly be set alight as happened in the recent case of the *Pacific Glory*. (Incidently, the oxygen content for the non-inerted ship in Table IV A would appear to be too low when compared with the theoretical for a mixture of hydrocarbon vapour (35·2 per cent) with air only; would the authors care to confirm this value?)

The main value of this paper was in emphasizing yet again the importance of actually monitoring tank atmospheres, surely a fundamental requirement of any gas control system. Indeed said Mr. Hosie, it was not overstating the case to suggest that onboard any oil tankship today, with or without gas control systems, a petroleum gas measuring device was no less important and valuable to the cargo control officer, who was normally the chief navigating officer, than his sextant. With both instruments it was essential that clear access be available to permit accurate assessment of the vessel's safety. It was particularly evident from Fig. 14 that access to all parts of very large cargo compartments had to be provided, since some of the hydrocarbon gas concentrations could be in the flammable range when those measured at a single location, such as a vent outlet or sighting port were not. With the fitting of fixed tank washing machines in certain new VLCCs there had been a noticeable reduction in available openings in the deck which used to be provided by ports for portable machines, and which could be used to sample in the far reaches of the tank.

While the main purpose of a gas control system was to prevent flammable atmospheres occurring particularly during the ballast voyage, the cargo tanks during this part of the transport cycle might have to be entered by personnel for inspection and maintenance work. In this event the tanks would require to be ventilated with air; but not only did there have to be sufficient oxygen for normal respiration, there also had to be less than the permissible limit of concentration of any toxic gas. Even for hydrocarbon vapours, which were anaesthetic rather than toxic, the maximum allowable concentration (MAC) which had been established medically was only 500 ppm, but for toxic gases much lower values were necessary. For example, the MAC for hydrogen sulphide, which was commonly, but not invariably, found in crude oil, was as low as 20 ppm. Since the venting with fresh air process illustrated in Fig. 12 was obviously a dilution process, wherein the oxygen content rose and the gas content fell exponentially, in the limit the tank would never be free of gas. It would be interesting to know what provision was made on the authors' ships to measure and control such low gas concentrations when entry into the tank was required.

The results plotted in Figs 12 and 14 were interesting since they emphasized the necessity, preparatory to designing a gas control system, of a thorough understanding of the motion and mixing of atmospheres with even small differences in their densities. Some years ago Mr. Hosie was involved in a study of gas exchange processes in the ventilation of cargo tanks (Ref. 10). Early in this work it had become evident that the effect of buoyancy was marked, which could not be ignored in dilution and was, of course, vital in displacement. It had been found that a certain minimum density ratio was required to ensure stable gas layering, and that the stability of this layering was very dependent on the rate of volume change in the tank and also the configuration and position, relative to the tank walls, of the replacement gas inlet(s). Thus, in the cases of gas exchange illustrated in Figs 13 and 15, he had found it somewhat difficult to reconcile the very pronounced tendency to layering in the former with the almost complete absence of stratification in the latter; for, although not available from the paper, the difference in density ratios in the two cases must have been very small indeed.

Finally, the authors had observed that the value placed upon safety always had to be a matter of judgement for the individual shipowner. This could well be true with regard to his investment, viz: the ship itself. However, there were an increasing number of those concerned who would not accept this philosophy in regard to the crews who manned such ships. Due to the design of oil tankships it was impossible to achieve the separation distances between flammable vapours and potential ignition sources that would obtain in land-based petroleum installations. Consequently, the tanker owner had a very special responsibility in ensuring that the maximum protection for human life was provided. This involved not only the provision of suitable equipment, but also, and just as important, satisfactory supervision to effectively operate and maintain this equipment efficiently. The authors would appear to have made a significant contribution in this direction.

Dr. C. T. Sutton, M.Com., D.Sc.(Econ) wrote that behind almost every paragraph of the paper was a complex of thinking and work that reflected a remarkably successful balancing between thoroughness of research, extent of research and appropriate economics, as well as between values and economics, and between primary and incidental aims.

This project had grown out of an extensive world-wide enquiry into tanker explosions. As a result of the many doubts surrounding these incidents and of the various suggestions raised, Mr. Sutton had been asked by BP Tanker management (primarily at the instigation of the Technical Director, Cdr. Platt) to head an enquiry into the potentialities of the inert gas system. Mr. Sutton mentioned this as his warrant for bringing up various points concerning the project's background that the authors had had to exclude because of the primary requirement of giving the most information in the briefest but clearest form to all who were interested.

The first point of note was the open international co-operation involved, starting with many American friends, including the BP French associates, and all those in different countries who showed interest, with particularly sustained interest in Norway through Det norske Veritas. Apart from the content of information given, such interest was always of great moral support in difficult work.

The second point to note was the enormous support given by BP Research Department, through the confident interest of its then head, Mr. P. Docksey. Two senior research associates—Dr. K. Brummage and Mr. J. Hyde, helped in particular with many research personnel supporting them. It would need many papers to clarify the extent and thoroughness of the work done concerning cargo gassing, explosion factors and corrosion factors. Each graph and table was the brief summary of long sustained, complex, and often trying work.

The third point concerned general personnel. Apart from the many in Head Office and at oil terminals who helped, a most striking feature was the enthusiastic co-operation of the fleet personnel. This was of the utmost importance, not merely from the research aspect of the project, but for the successful operation of the system onboard. It was again impossible to mention all fleet workers, but the atmosphere of their work was epitomized in the person of Mr. Day, the chief engineer on one of the first ships fitted experimentally, whose immediate enthusiasm and close practical attention were such that he was brought ashore to join the project team, with one of his primary duties being to ensure that fleet personnel were kept closely informed and their enthusiastic attention co-ordinated.

He hoped it would not sound presumptuous on his part to congratulate and thank Cdr. Platt both for his sustained encouragement and confidence from the first suggestions of the project, and for the truly scientific integrity in having Mr. Day's name first on the list of authors—with the more than willing agreement of Mr. Telfer the naval architect who, apart from other valuable work, directed in particular the extremely difficult corrosion assessment.

The type of thinking deficiencies that led to the disastrously unnecessary consequences of the early introduction of radar had to be avoided. It could be dangerous merely to buy some inert gas system and leave it at that. The design specification was of paramount importance and all requirements had to be thoroughly understood when ordered. Following this, it had to be certain that all working personnel were given full instructions. To go with this there had to be continuing co-ordination between Head Office and ship personnel. There were many incidental advantages to be had from this beyond more fully ensuring safety. It was to help with ensuring satisfactory design that BP patented the system, but granted its free use.

By common agreement every kind of possible objection to the system (and there had been many) was deliberately sought out and treated in the enquiry as focal points for attention. It was dangerous to dismiss objections, but it would have been all too easy to let them become over-riding. Secondly, there had to be a completely open-minded attitude as to failures or unexpected difficulties in the work and entire avoidance of any over-emphasis of desired results. That these were obvious scientific requirements did not lessen the value of stressing them in specific words. He was convinced that the principles had been continued throughout and that this paper represented not merely a clear and full account of all relevant points, but that it was a wholly objective and modest presentation of them.

One point of interest was that, owing to many initial opinions against the system, the enquiry began as one into the potentialities for inhibiting corrosion, with the general idea that anything approaching a 25 per cent improvement might largely pay for the system, while no claims needed to be advertised as to its efficacy as a safety factor. It was Mr. Day's initial enthusiasm for the safety potentialities, almost disregarding corrosion, that rapidly shifted the emphasis of the objectives.

Mr. K. Watson, C.Eng., M.I.Mar.E., wrote that in section 7.2 the authors had referred to problems encountered with the quality of combustion in auxiliary boiler furnaces when steam demand was minimized by the use either of a Diesel generator or by an adequate amount of steam being produced for the turbo generator by the main engine waste heat recovery system. It had been normal practice, it was stated, to artificially load the boiler by pumping sea to sea at a rate sufficient to generate inert gas of suitable quality.

Some two years ago this problem had been studied in depth and a scheme devised to provide, in addition to the main burners, a small fully automatic "booster" burner complete with its own fan and combustion control system. This burner was designed to produce, on high flame, steam equal to five per cent of the boiler capacity and, at this level, to generate flue gas with an acceptably low oxygen content.

One of the problems which had occurred in earlier developments, where the small burner had been run without automatic compensation of the combustion air pressure, was that changes in furnace pressures resulted in a breakdown of the correct fuel to air ratios; this problem has been overcome by providing the booster burner with its own self-compensating combustion controller as referred to above. This controller ensured the availability of good quality gas even under extremely low steam load conditions. This availability was extremely important as tank topping up was required at sea when steam demand was negligible.

In the event of steam demand increasing due to tank washing taking place or, the main engines slow down reducing the amount of steam available from the waste heat recovery system, then, on a predetermined pressure drop within the boiler drum, one of the main burners would be brought into operation. A built in trip circuit automatically cut out and secured the booster burner.

When cargo pumping, one or both main burners would be brought automatically into operation and no problems were encountered in maintaining the oxygen levels indicated in Table XI.

Mr. G. C. Blake, B.Sc., C.Eng., M.R.I.N.A., A.M.I.Mar.E. wrote that the authors had dealt extensively with gas concentrations in cargo tanks under various conditions and had stated in section 3.4.1., " . . . that after discharge of cargo, the evolution of hydrocarbon gas is very slow." Their findings did not correspond with the results published by Logan and Drinkwater, who had found that not only did the gas concentration vary with the cargo and the time of year, but more significantly, they found that there was an increase in gas concentration of from three to eight times the L.E.L. in the first two-to-three days after a winter discharge of Kuwait crude (Fig. 29). Such an occurrence would, apparently, lead to the point "D" in Fig. 10 moving across the critical dilution line once more, unless the tanks were purged twice—once on leaving port and again when the atmosphere had "stabilized".

A great deal of data had been provided to show the marked reduction in the corrosion rate which could be expected when an inert gas system was fitted. The authors mentioned in the text that six tanks were left non-inerted in *British Prestige* to enable a direct comparison to be made with the inerted tanks. None of the results of this comparison had been included in the tabulations,

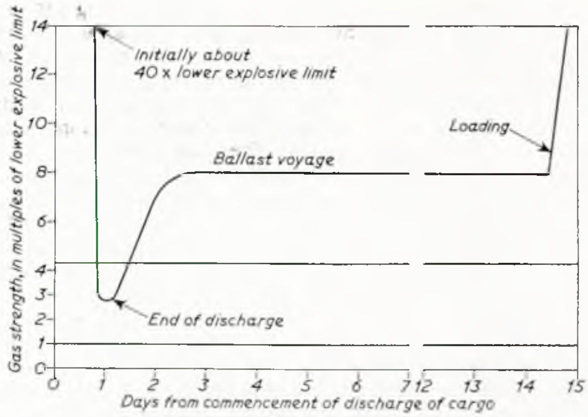

Fig. 29—*Tank battened down after discharge—no washing or gas freezing (winter) s.t.s. Zaphon*

and it would be of considerable interest if the figures obtained could be made available.

In view of the significant relationship which the authors had noted between the corrosion rate and the time a tank spends empty, there would appear to be a valid argument for connecting the clean ballast tanks to the inert gas system. This would result in considerable savings in the case of the writer's company, where these spaces were 100 per cent epoxy coated. To overcome any risk of contaminating the ballast spaces with cargo, the tap-off point would have to be placed upstream of the deck seal. This would, presumably, also allow the ballast spaces to retain their exemption for admeasurement purposes. Had the authors given consideration to providing such a connexion?

During discussions with shipyards regarding inert gas systems, the possibility of the acidic scrubber effluent being regarded as a harbour pollutant in the future had been raised. Did the authors consider this to be a real problem and, if so, had they any thoughts as to how best it could be overcome?

The cost of £150 000 quoted for an installation in a 250 000 dwt tanker represented about 1 per cent of the ship's cost at current prices, and owners were entitled to look for some tangible return on an investment of this magnitude. While the authors had made a strong case for an installation purely on the basis of corrosion reduction, this could be done equally effectively, and perhaps more economically, by applying suitable coatings.

The real benefit was, unquestionably, increased safety. To date, however, marine underwriters had declined to offer any reduction in premium to owners who had fitted inert gas. The data presented in this paper should go a long way toward convincing underwriters that an inert gas system measurably reduced their risks, and that those owners who made installations of this type were entitled to a reduction in premium.

Mr. Dale E. McDaniel wrote that in describing the safety benefits of an inert gas system, the authors had correctly identified this system as a preventive measure. Mr. McDaniel would not attempt to deal with the question of the relative merits of inert gas as a preventive measure. A properly operated inert gas system was certainly an effective preventive technique.

Unfortunately, the authors had done little to clarify what had always been a rather hazy line separating tanker fire prevention and fire extinction. They had indicated that the system served to replace the statutory fixed *fire smothering* system, and yet went on to say that the inert gas system was preventive. In his opinion, and he believed in the authors', prevention and extinction were not synonymous.

Part of the confusion stemmed from statutory requirements begat by the International Convention for the Safety of Life at Sea, 1960, which called for fitting of a smothering gas or steam system, but allowed substitution of an internal or external foam system (Chap. II, Reg. 65 (f) (i) and (ii)). Similar requirements were in effect in the United States until 1 January, 1962 when the fitting of an external foam system was made mandatory.

Steam or smothering gas systems were obviously only effective in intact tanks, and were activated only in event of imminent or actual disaster.

Since fires, as opposed to explosions, in *intact* tanks were virtually non-existent owing to the lack of sufficient oxygen within the tank, smothering gas could not really be considered to be an extinguishing system. At best, smothering systems were a mixed preventive and extinguishing measure, with few of the virtues of either. Continuously operated inert gas systems were vastly superior as a preventive technique.

The deck foam system was totally different. It was primarily a fire *extinguishing* system. In the United States, it had been developed by considerable research and practical evaluation aimed at producing an effective fire extinguishing system for tankers. Foam was applied outside of the tanks from monitors and / or hand-held appliances, giving very flexible extinguishing capability. Technical improvements in both foam concentrates and equipment had overcome difficulties that plagued the early shipboard foam systems. Modern systems were both reliable and effective. They overcame all of the five deficiencies alleged by the authors (section 3.1) with the exception of (i) and (ii) which in fact were not valid objections. With respect to the first "deficiency", it was true that a foam system had time-limited capability, but a foam system was not nearly so limited as the portable devices favoured by the authors for *extinguishing* purposes. With respect to the second "deficiency", it had to be agreed that foam systems had little practical fire prevention value. It was not designed primarily for preventive purposes. It could equally be held that an inerting system had little practical extinguishing value.

There were a number of emergency situations in which the inert gas system would not prevent a fire. These included such incidents as collisions involving a loaded tank vessel (shown by one survey to have been the cause of 218 of 330 tanker deaths during the reporting period) and deck spills. Experience had been gained in use of deck foam systems in both of these types of casualties. For example, in the case of one spill fire involving a tank vessel and a lighter, the fire was extinguished just as the foam concentrate was exhausted. In the case of a collision between two tankers, the system did not extinguish the fire but was instrumental in its control.

In view of the potentially catastrophic consequences of such fires, it seemed only prudent to provide an effective *extinguishing* system. Inerting as a *preventive* measure served an entirely different purpose. For these reasons Mr. McDaniel could not concur in the authors' opinion that portable extinguishers were all the extinguishing protection needed aboard inerted vessels besides the firemain, which provided only cooling.

Mr. M. Tani, C.Eng., F.R.I.N.A., wrote that the authors' paper had been greatly appreciated in Japan; it was very useful since interest in the inert gas system had increased there following the recent tanker explosions.

Although the paper contained information on the effectiveness of the purge pipe could the authors say more about: features of hull construction and the arrangement of purge pipe for the test ship; the air change or vapour purge between transverse webs (bottom or deck) and fore and aft of swash bulkhead; and the recommended design basis of the purge pipe (pipe diameter and height above upper deck)?

Regarding the safety aspect, assuming the inert gas system was installed on a ship without a fixed tank cleaning system, the authors' views on any possible hazardous or harmful human effects would be welcomed.

Mr. John Hyde wrote that the inert gas system described in the paper went further than other systems in providing safe tank atmospheres during all phases of operation. However, since the cost of installing the system was significant there would undoubtedly be differing philosophies among tanker owners, especially the independents, concerning installation costs and maintenance costs against varying degrees of safety. This equation would most probably be balanced by probabilities of certain incidents occurring and probabilities of explosion and/or fire when they occurred. To be sure, most people, and in particular shipowners, would not spend money until it proved absolutely necessary, even when long term savings could justify the expenditure, savings such as the benefit of gaining some control on corrosion and shorter discharge times. It should be noted that at least one U.S. operator installed a system to supply tanks with flue gas for the sole purpose of preventing condensation in tanks carrying lube oils.

The authors had mentioned that in some instances, such as "Dead Slow Ahead" in steamships and in general operation in motor ships, the boilers had to be artificially loaded to obtain sufficient quantities of good quality gas. Were there any figures available concerning the costs of such operations in terms of fuel consumption for various ship deadweights?

It was interesting to note that although the inert gas system met British statutory requirements as a fixed fire smothering system, the U.S. Coast Guard, as yet, did not approve it as such. Since it was mandatory for U.S.C.G. approved tankers to be fitted with fixed deck foam systems, the inclusion of an inert gas system and exclusion of a foam system in future U.S. vessels might not present such a financial burden if the U.S.C.G. would allow its use in lieu of the foam system. At present, the U.S.C.G. was considering increasing the scope of fixed foam systems.

With ecology being a key word these days, and the maintenance of the natural environment the objective of concerned governments, then maximum safety for tankers, especially those in the "Jumbo" category, was of prime importance. From this standpoint alone, it would seem prudent to provide for safe cargoes at all times by using available techniques such as the inert gas system.

Mr. W. J. Ferguson, C.Eng., M.R.I.N.A., wrote that the authors were to be congratulated on their concise and interesting paper in which they discussed the development and operation of an inert gas system incorporating purge piping for each cargo tank.

It had recently been reported that some tanker operators did not incorporate purge piping in inert gas systems but utilized the cargo piping and existing deck openings for the purging of tanks. It would be interesting therefore if the authors would give their views on the advantages and disadvantages of fitting separate purge pipes.

Commander L. K. D. Wood, M.B.E., R.N., C.Eng., M.I.Mar.E., wrote that the authors had made their paper so factual and almost non-controversial that it was difficult to criticise it. However, in view of his own decade of discussion and collaboration with them on this matter Cdr. Wood thought they would expect him to make some effort at constructive criticism.

The authors described the fan-motor combination, or as he would say, the blower, as the heart of the system. This he thought was an apt analogy for which he was grateful, and which he would pursue. Indeed if the heart or blower failed so did the body or the system, but a good heart would last some three score years and ten, or more if well cared for, and a good blower should last the life of a ship. The acid-proof internals and lining of a stomach or scrubber had to be of a high enough standard not to perforate or there would be dire consequences. The muscles and nerves or control gear also played their vital part. Above all there was the need for sensible human care of the body or system.

The authors' company had obtained its blowers fairly evenly from two U.K. fan manufacturers which had had wide experience in the field and sound reputations. It would be difficult for such firms to supply anything but good blowers but possibly some designs had been better than others.

Recently Cdr. Wood had witnessed the first opening up of one ship's set of two inert gas blowers after three years of regular use. They were in good order, appeared to be pretty well "fit and forget" machines and needed no more than a little repair of corroded or eroded steelwork.

It was this corrosion/erosion attack which was the bane of marine inert gas blowers. In spite of the best efforts towards demisting or disentrainment of scrubber water, such blowers could receive a 45 m/h horticultural spray of pH.2 sea water into their 3550 rev/min runners. Steel, even when coated with tough material, did not last much over a year under such attack. The authors now pinned their faith on nickel aluminium bronze runners but it took Cdr. Wood three years experience and a further three years persuasion to attain this. He wondered if they would accept that aluminium silicon magnesium alloy in the fully heated treated condition was as good. This was important because the source of aluminium bronze in the U.K. had been and still was somewhat restricted.

However, both the materials he mentioned required expert design stressing and expert welding fabrication for use in marine inert gas high speed blowers. These indeed could be just mere fans but couldn't be any old fan. They required sophisticated design and manufacture.

The authors indicated their dislike of a blower unit of fan casing and runner mounted overhung and close coupled on the driving member and its shaft. Such blowers of course had given trouble when the motor was not adequate for the job. Robust motors with properly designed and spring-loaded bearings had proved to be trouble free over many years of use in this combination with the fan. A turbine with pressure-fed oil lubricated sleeve bearings had proved itself, in hundreds of installations, well able to carry the close coupled fan and overhung runner. Cdr. Wood himself would advocate the minimum number of bearings to maintain, provided they were good bearings in the first place and the fan runner was kept clean and in good balance.

There had been some doubt as to the best type of scrubber for marine inert gas systems. This need not have arisen in view of industry's years of informed experience of gas cleaning. The basic issue had been clouded and confused by efforts in some quarters to establish the "best" marine inert gas system. However, now, the discerning understood that marine inert gas systems using boiler flue gas differed little in concept from boiler uptakes to cargo tanks, all simple pipe lines in which were inserted scrubber and blower and non-return devices and valves plus some control gear and safety devices. The "best" system was that in which these inserted items were individually selected to be of the highest standard.

When one considered the appreciable overall cost of installing a marine inert gas system it would appear to be unwise cheeseparing to use equipment not of the highest efficiency in scrubbing or not of the highest standard of supply.

The authors had indicated their preference, at least for product carriers, of the bubble tray scrubber. Of course it was their own "baby", was adequate, and could be produced more cheaply than the higher efficiency designs. However, it would appear to be somewhat unfair to the latter to infer that it gave the cleaner gas.

Long experience in industrial gas cleaning awarded the highest cleaning efficiency to scrubbers using impingement and Venturi techniques with the packed tower employed in less exacting roles and the bubble tray kept to its appropriate role of liquid fractionation.

It seemed strange that in a paper so full of facts regarding important tests there was no mention of rigorous tests to establish the relative gas cleaning performance of the several types of scrubbers fitted in the ships of the authors' company. Possibly the authors considered that gas cleanliness was not all that important provided it was barely adequate. Others dealing with marine inert gas systems desired the highest available standard of gas cleaning. Who was to say which was the better view?

Mr. G. Victory, C.Eng., F.I.Mech.E., M.I.Mar.E. wrote that he would like to compliment the authors of this paper on producing such a comprehensive and lucid description of the inert gas system at a time when the avoidance of explosions within the cargo tanks of crude carriers was commanding such attention. It was of interest that the added safety of such a system extended beyond the tank washing procedure, on which the greatest effort was being deployed, and could protect the vessel against the hazard of fire and explosion due to collision and grounding.

There were very few facts in the paper to which exception could be taken wrote Mr. Victory, who could only point to one or two factors which might have been left out in order to prevent the paper becoming too long.

1) In section 3.1 it was mentioned that the MS Fire Appliance Rules 1965 would permit an inert gas system which filled a tank in 240 minutes. This had to be considered in conjunction with the fact that the essential consideration was the requirement for a fire extinguishing system, not an inerting system and that this figure applied essentially to a general cargo type of ship. Such a time scale would never be considered adequate for inerting in a tanker. In the same section it was pointed out that the dangers of static generation when attempting to inert any space containing hydrocarbon vapours by the injection of CO_2 had not been stressed. Attention would be drawn to this hazard in the new DTI draft Instructions to Surveyors which were approaching the printing stage.

2) In section 3.3 the authors referred to the purging of vapours which could pass through the flammable range during the dilution phase. The purge pipes were shown to be placed at the after end of the tanks (Figs 1, 4, 5 etc), and it would be better if such vapour discharge was released well forward of the accommodation and pump room. Thus it would be preferable for the aftermost pipes to have a deck extension for some 50 ft forward to avoid such a possibility. The possibility of using drop lines, where fitted for the purging could be considered, as the gas release through the loading manifold would be in a safer area and not so liable to cause carry-over of loose oil and consequent fouling of the decks with the possibility of pollution.

3) In section 3.4.2.2 the authors had referred to the IOTTSG recommendations relating to the siting of tank vent outlets, but not to the need for these to be of the high velocity type which was an intrinsic part of the safety assessment.

4) Whilst admittedly of less importance than the inerting or the purging of the tank after discharge the ability to inert the tank before loading when new or after tank inspection might have been mentioned in conjunction with the venting operation (Fig. 12). For the operation of inerting a gas freed tank the ability to inject the heavier inert gas at the lower part and to exhaust the air by displacement at the upper part of the tank would be a useful function in reducing the time required for this operation. This advantage however did not appear to be very important, certainly not enough to over-ride the advantages which delivery at the top of the tank had for inerting during discharge or normal purging.

5) As a practical marine engineer one had to admit that the co-operation between deck and engine room was not always perfect and it would appear that, apart from an alarm if the gas quality was not maintained—and this could be shut off in an emergency by the engine room staff—the officer in charge of the cargo operations took the quality of the gas being supplied very much "on trust". This might be the reason for the oft quoted comment that the inert gas system can give a false sense of security. It would appear therefore that the need to ensure without any doubt that inert gas of correct quality, at an adequate pressure and appropriate temperature was available at the deck main throughout the discharge period, required more positive supervision than was provided by the sensing point referred to in the final paragraph of section 11. This was presumably used for check tests with portable apparatus, and as such would be used only at relatively infrequent intervals, so that the detection of any fault or breakdown of quality between the engine room and the deck main could take some time. Complete security could be ensured if instruments in the cargo control station monitored the gas at the deck main sampling point and produced a continuous chart of pressure, oxygen content and temperature during the discharge period. This chart would be available for rapid checking and recording for subsequent interpretation. Should the criteria be outside accepted figures at any stage in the discharge then such a chart would indicate the need for adequate purging of certain tanks before they could be considered properly inerted. This comparatively cheap addition to the instrumentation would, Mr. Victory considered, ease the deck work as it would not be necessary to

obtain check readings. If the chart were kept with the ship's papers, the satisfactory operation of the inert gas system could be easily checked by the superintending staff and would effectively eliminate the chance of a false sense of security being engendered by the use of the inert gas system.

Mr. Hans G. Frisk said that since the beginning of the 1960s his company had installed inert gas plants in tankers. The design and supply of the main parts of these plants had been entrusted to different subcontractors. The experience from the installations during the first few years was very different. The failures which occurred on these tankers were in most cases due to poor design or the use of unsuitable materials in the scrubber or fans.

Efforts made during recent years to improve the design and materials in these important parts of the systems had given good results. In this respect it was felt that the efforts made by the authors' company have been very successful.

The recent tanker explosions had increased the demand for tanker safety equipment and some people were of the opinion that an inert gas system was a good solution.

Nevertheless many shipowners hesitated when discussing inert gas installations. Mr. Frisk felt that in most cases this was due to the complexity of the systems and to apprehension concerning maintenance problems. The best way to overcome the reluctance among owners and to make tankers safer was to simplify the installations. He thought that this was the most important task for shipowners, shipyards and subcontractors in the inert gas field in the immediate future.

Mr. J. Th. Wilse, C.Eng., F.R.I.N.A. said that this paper had been read with great interest and was expected to be used as a source of reference for several years to come. The way the information was presented revealed a close and practical knowledge in the field. It was appreciated when the authors, at the end of their paper, said that their work was a response to requests from all over the world for information on inert gas.

Contrary to most information received today, this paper also discussed mishaps and breakdowns. Information about "weak points" was obviously of particular interest to superintendents and surveyors, but was often treated as "top secret". Credit was therefore given to the authors as well as to BP Tankers for this comprehensive and informative paper.

Det norske Veritas (N.V.) introduced their first Rules for Inert Gas Plants in 1964. Based on experience—particularly "weak points"—revised rules were issued in 1970 and 1971. Mr. Wilse was glad to say that the present rules contained all main requirements referred to in the paper.

With regard to system capacity, N.V. Rules (Chapt. XIV, sec. 10) required at least 1·25 times the total capacity of the cargo oil pumps. This seemed high compared with the IMCO suggestion of 10 per cent "reserve capacity" (FP XI/11). It was therefore pleasing to learn that the authors based their systems on 1·33 times the maximum pumping rate.

When comparing the above three factors, it was presumed that the required maximum cargo pumping rate referred to specified backpressure, for instance 10 kg/cm² (140 lb/in²) at ship's manifold. It was further presumed that modern centrifugal pumps with deliveries in the range 2000–5000 water tons per hour were used, all having approximately similar delivery/head curves.

Based on the above, some consideration could be given to possible pumping capacity with actual backpressure reported in service, normal or not, i.e.:

Pernis	5 kg/cm² (70 lb/in²)
Slagen	5 kg/cm² (70 lb/in²)
Wilhelmshafen	5·5 kg/cm² (80 lb/in²)
Isle of Grain	8 kg/cm² (115 lb/in²)
Gothenburg	8 kg/cm² (115 lb/in²)
Portland, Maine	9 kg/cm² (130 lb/in²)
Milford Haven	10 kg/cm² (140 lb/in²)

This means that a backpressure of only 50 per cent of designed value could be expected at certain ports.

By comparing a number of pump delivery curves, it seemed that maximum delivery increased by 25–50 per cent under such conditions.

For the sake of good order it had to be mentioned that neither pump cavitation nor monitored delivery was accounted for. This involved a certain uncalculated reduction in delivery.

If the capacity of the inert gas system was to be based on the cargo pumping rate, the authors' specification seemed very realistic.

Another item which called for attention was the operation of the soot blowers. Why was an interlocking device not mandatory in order to prevent operation of the soot blowers when the uptake valve was open? According to the paper, such interlocking devices had been arranged on some vessels. Were there certain reasons for omitting this fairly simple but nevertheless efficient safety measure?

Finally, inert gas systems onboard OBO carriers should be mentioned. A number of explosions onboard OBOs had taken place in cargo holds partly filled with dirty ballast water. The actual reason for these explosions had not yet been established and would not be discussed here.

Preference for certain cleaning conditions had however been voiced from time to time. In this connexion, it should be emphasized that, as far as was known no OBO explosion had taken place in a tank where washing was taking place. The atmosphere in the tanks prior to washing was therefore brought into focus, and as a result, it appeared that inert gas was particularly suitable for OBO ships.

On such ships the main line on deck would have to be arranged lower than the level of cargo within the hatchcoaming. A certain risk of accumulation of liquid in the mainline was therefore present and had to be considered.

Further, the OBO ship was usually built with the lowest possible masts and posts. Gas venting through the mainline at mastheads in these cases was not practicable. Venting might have to take place through high velocity jet valves at each hatch. This however should not be a disadvantage either to inert gas or to the venting system.

REFERENCES

9) Logan, A. "Experiences with Gas Control in Crude Oil Carriers", *Trans. I.Mar.E.*, Vol. 76, 1964, p. 25.

10) Hosie, R. M. and Sommer, P. H. J. "The Ventilation of Cargo Spaces in Oil Tankers", *BSRA Report* NS 164, 1967.

Authors' Reply

In reply to Mr. Kennett the authors wrote that as a shipyard chemist Mr. Kennett had confirmed that an inerted vessel would be acceptable for drydock, including inspection of painting. Regarding the difficulty of measuring oxygen, the authors presumed this referred to the analysis rather than the obtaining of the sample. The instruments described in the paper were normally fitted with drying tubes and therefore gave the percentage oxygen or CO_2 on a water-free basis.

In reply to Mr. Hosie the authors wrote that as the inert gas system prevented explosions regardless of the hydrocarbon gas concentration, they had made only passing reference to the "too lean" or "too rich" methods. This said, the authors doubted whether the "too lean" or "too rich" methods could be applied in practice to all cycles of tanker operation. Even in principle it was difficult to see how the "too lean" method could be applied during loading, loaded passage or during the discharging of cargo. Artificial enrichment of the tank atmosphere would be necessary when using the "too rich" method in the ballast passage, and apart from other practical difficulties, this would be unacceptable with refined products.

The inert gas system was certainly not a "cure all", and the authors had not claimed that it was for the particular case of collision in the loaded condition. It was effective as a safety measure in the loaded passage and during loading and discharge of cargo. Although the atmosphere in tanks containing crude oil was likely to be too rich in hydrocarbons to support combustion, flammable concentrations were possible above certain refined products of low vapour pressure. In partly filled tanks air could be drawn in due to diurnal temperature variations. In these cases the addition of inert gas provided a degree of safety not found with other systems.

The conditions following collision were random and complex and the following paragraphs could do no more than examine certain possibilities.

The authors agreed that high hydrocarbon gas concentrations were likely to pass through the flammable range on dilution with air; but if the cargo tanks were under pressure of inert gas, it was less probable that a tank ruptured in collision would catch fire, and less probable that escaping gases would be ignited by "red hot metal" at the point of rendering. The residual pressure in the tanks would take a certain length of time to relieve, depending of course on the size of the hole. During this time the inert gas system could be started, and some cooling of the plates would take place. Once the oil escaped from the struck vessel, the ignition of this oil could be outside the control of the vessel, and in this sense the inert gas could only be expected to prevent flash back to the ship.

Even though a tanker was in a loaded condition for nearly half its life, the risk of collision was highest for the short periods whilst entering or leaving confined waters. The figures in table 15 were derived from Ref. 11 quoted at the end of this reply.

The figures for "tankers burnt" excluded vessels lost by fire following collision. They also excluded cases where the fire did not result in the loss of the vessel. None of these figures necessarily reflected the loss of life involved. They did show that the risk of loss of a tanker by collision was less than on dry cargo vessels. The figures also strongly suggested that the presence of an "over rich" atmosphere could not be guaranteed in the loaded condition. Of the tankers lost by burning, excluding those under repair, the presence of inert gas should therefore have greatly reduced the total. It seemed reasonable to conclude that inert gas should provide a greater degree of safety even in the loaded condition. The consequences of collision in the loaded condition were problematical, but in the ballast condition, provided the tanks had been purged, there should be a significant improvement in the safety of a vessel in collision. Consequently, the authors were convinced that the inert gas system was likely to prevent fire and explosion over a wider range of collision circumstances than any other known system.

The authors confirmed that the low oxygen content noted in Table 4A for the *British Statesman* was correct. CO_2 readily

TABLE XV—SHIP LOSSES, 1949-66

		Ships	Percentage at Risk	Ships at Risk
LOSSES BY COLLISIONS 1949-66				
Dry Cargo Ships		293	0·092	320 104
Tankers		31	0·044	70 194
Of the 31 tankers, 13 were ultimately lost by fire				
LOSSES BY FIRE 1949-66				
Dry Cargo Ships:	in port	70	0·022	
	at sea	126	0·039	
Tankers:	in port	29	0·041	
	at sea	17	0·024	

TANKERS BURNT 1949-66 (excluding collision fires)

In Port

	Discharging	Loading	Loaded	In Ballast	Cleaning Tanks	Under Repair
Totals lost	5	5	8	3	4	4

At Sea

	Load	Ballast
Totals Lost	11	6

dissolved in crude oil, and to a lesser extent this was true of oxygen. The principal reason for the depletion of oxygen was considered to be the reaction with hydrogen sulphide contained in crude oil. The hydrogen sulphide content of crudes shipped by BP met the limits of 40 ppm and 70 ppm in the Eastern Mediterranean and Middle East terminals respectively.

From measurements, a crude oil containing 50 ppm H_2S, would be expected to give rise to about 700 ppm H_2S in the ullage space of a loaded tank. On discharge, the H_2S in the ullage space would be diluted at least ten times (according to the ratio of ullage to total tank depth) thus reducing the H_2S concentration to 70 ppm. On gas freeing, the hydrocarbon gas concentration in such an empty tank would be reduced to below the L.E.L. requiring about a ten to one dilution. Consequently, the H_2S concentration would be similarly reduced to 7 ppm, which would be below its T.L.V. In practice, gas freeing for entry was continued until the hydrocarbon gas concentration in the tank could no longer be detected on a combustible gas indicator and the O_2 content was restored to 21 per cent by volume.

Mr. Hosie had emphasised the importance of the relative positions of the tank inlets and exhaust. The authors had shown that the purge pipe, properly positioned, was a safe indicator of the tank atmosphere, particularly when the gas emitted was within 1 per cent of that being supplied. In inerted tanks, it was not of fundamental importance if some hydrocarbon gas remained before tank washing. It was desirable, but not fundamental to the safety provided by the inert gas system, to purge the hydrocarbon gas content below that defined by line AB in Fig. 10. When the "too lean" system was being used, great care had to be taken to remove the maximum quantity of hydrocarbon gases as the difficulties of monitoring all areas of these large tanks were apparent. Nevertheless, good mixing should occur in a tank if sufficient fans giving both high volume change and inlet velocity were provided. When good mixing occurred, a single position in the tank would provide typical samples particularly if high and low level readings were taken. The authors did not recommend as a normal practice the monitoring of a large number of positions in the length and breadth of a tank, as this increased the amount of human activity in a dangerous area. The additional work load might lead to greater fatigue and risk of human error.

The marked influence on layering of small differences in density was indeed surprising. However, it could be anticipated that a pure displacement action would occur when the direction of gas flow was opposed by buoyancy, but the interface of the two gases would oscillate the more violently the closer the densities were together. The interface of the gases could be caused to oscillate more violently by high inlet gas velocity, the velocity required being greater the greater the difference in density. If the inlet gas supplied from the top of the tank was denser than the tank contents, it should fall and mix naturally. It would seem therefore, that the rate of volume change was only one parameter, and that the entry gas velocity had also to be included in determining the minimum density ratio for stable layering.

In respect of the statement criticised by Mr. Hosie "that the value placed upon safety must always be a matter of judgement for the individual shipowner" some comment was required. All owners had to comply with the requirements of the regulatory bodies, but it was the extent to which they exceeded these requirements, applying voluntarily their own safety regulations, or accepting the apparently more expensive legal alternatives which exercised their moral and commercial judgement on safety matters. Finally, it had to be said that even when the best possible safety equipment was supplied, the safety of the ships' personnel was ultimately in their own hands, and was determined by the efficiency with which the equipment was operated.

In reply to Mr. Watson the authors endorsed his comments on the use of the small booster burner to generate low oxygen inert gas. The proposed system, although unproven by their company, was nevertheless a step in the right direction. The possible use of this equipment was described in the reply to Mr. Hyde. In future product carriers, booster burners of this type would be used, which besides generating high quality inert gas should also supplement the waste heat recovery system at sea.

Mr. Blake doubted whether the evolution of hydrocarbons was very slow. In reply, the authors suggested that Fig. 23 represented the tendency of the tank atmosphere to homogenize, rather than indicating the evolution of hydrocarbons. Plotting the values at mid tank depth given in Table 5 of the present paper would show similar trends to Fig. 23, but the values at 88 ft depth would reveal a *reduction* in hydrocarbon gas concentration over the period of measurement. The values given in Table 5 *taken as a whole* indicated the tendency of the hydrocarbon contents to come to a steady value of about 7 per cent by volume. In the same table, it could be deduced that immediately after discharge about 90 per cent of the tank had a hydrocarbon content of 3 per cent, whilst the remaining 10 per cent at the bottom of the tank had a hydrocarbon concentration of 54 per cent by volume. The average percentage by volume of the hydrocarbon gases in this tank would therefore have been about 8 per cent. After 63 hours, the average value in this tank was about 7½ per cent, indicating possibly a slight loss in the total hydrocarbon gas content. This rough estimation did not preclude the possibility of a slight gain in hydrocarbon content, but if so it must have been very slow.

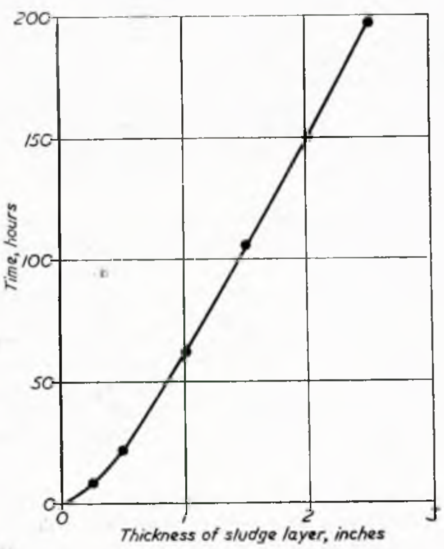

FIG. 30—*Time to degas sludge from Kuwait crude in the laboratory*

The effect of sludge on the evolution of hydrocarbons was also dealt with in Ref. 1, and Fig. 19 of that paper is reproduced here as Fig. 30. In commenting on this figure, Logan and Drinkwater had stated, "It was subsequently found in the laboratory that gas evaporates only slowly from thick layers of sludge taken from these tanks". They had also found that a gas freed unwashed tank took 3½ days after battening down to reach 70 per cent L.E.L. Further confirmation of the present work was indicated in Ref. 1, when it stated that the majority of hydrocarbon gases contained in sludge were released during tank washing to give a maximum increase in mixture strength of 100 per cent L.E.L. (1½ to 2 per cent hydrocarbon gases). Consequently, if tanks were purged with inert gas, little further evolution of hydrocarbon gases would be expected prior to tank washing.

The comparison of the corrosion rates between the inerted and strictly comparable non-inerted tanks on the *British Prestige* was given below.

TABLE XVI

	Inerted	*Non Inerted*
Ultrasonic mean ullage thickness loss per annum	0·0034 in	0·0058 in
Test plate mean ullage thickness loss per annum	0·0039 in	0·0065 in
Scale lifted (6 tanks in 5 years)	4·5 tons	7·5 tons

The authors emphasised the penultimate paragraphs of Sections 4.2 and 4.3, from which it would be inferred that the data obtained was insufficient to predict the corrosion rates for particular conditions of clean ballast, empty tank time, dirty ballast time, etc., in particular tanks. This applied particularly to the comparison of the very low corrosion rates measured in the after tanks of *British Prestige*, where instrument and initial reading errors were of comparable magnitude to annual corrosion rates.

As the authors had not connected inert gas to permanent water ballast tanks, they could only surmise that significant reductions in corrosion would be possible in these tanks by using inert gas. They had observed, however, very heavy corrosion on uncoated bulkheads adjoining the relatively warm cargo tanks, even though the zinc anodes had protected the supporting structure very well. It would be prudent, therefore, to continue coating the bulkhead plating of the permanent water ballast tanks and fitting the anodes even if inert gas were supplied to these tanks. There would still be a significant reduction in coating costs on the deck head, shell and bulkhead stiffening members.

They had been reluctant to connect the permanent ballast tanks to the inert gas system, although it was now understood that the tonnage penalty need not apply if they were. These tanks were being filled with ballast when the cargo tanks were being emptied and vice versa, and this could introduce a further degree of operational complexity. It also introduced hydrocarbon gases into spaces which otherwise would be gas-free, unless, as Mr. Blake had suggested, a separate line were fitted. The cost of this line would offset the savings made by reducing the coatings.

The authors had no evidence to suggest that the scrubber effluent would constitute a significant pollutent to harbour waters. The sulphur dioxide in flue gases of ships was normally dissipated into the atmosphere as atmospheric pollution. It could be argued therefore that the scrubbing of a proportion of these gases on inerted vessels contributed to a reduction in atmospheric pollution at the expense of a negligible increase in harbour pollution. The pH of the scrubber effluent was about

2½, but it would appear that this was almost instantly diluted by the sea water when it left the ship. It should be noted that sea water was usually slightly alkaline having a pH of about 7·8. Inerted vessels did not require any more frequent external anodes renewals than a non-inerted ship, and no sign of abnormal corrosion was observed on the shell plating below the scrubber outlet. No reduction in the deposit of weed or shell fouling had been observed on vessels fitted with inert gas systems compared with those which were not; and no changes in the intensity of fouling deposits were noted in the vicinity of the scrubber outlet. Although the authors had no evidence that this was "a real problem", measurements were being taken of the contents of certain harbour waters, but this long term project was unlikely to yield instant answers.

Basically there were two ways to overcome the problem should it arise and these were:

a) to remove the sulphur from the fuel,
or
b) to neutralize the sulphuric acid in the effluent.

The choice of neutralization of this acid could raise new pollution problems, particularly if the dosage rate of the alkali addition was not reliably controlled in relation to the SO_2 content of the flue gases.

They did not dispute the effectiveness of coatings, but would associate them with higher ultimate maintenance costs than inert gas systems. The initial cost of a coating system could be comparable with the inert gas system, particularly when the more expensive methods of application and preparation were considered. However, the purpose of quoting the corrosion reduction and other benefits was to show that the high cost of the inert gas systems, unlike other systems, could be offset by the reduction of capital and running expenses in other directions. Many companies fitted a closed loading system, and for these companies the additional cost for an inert gas system would be considerably less than the £150 000 quoted.

In reply to Mr. McDaniel who was concerned to see that adequate means of fire extinguishing were also fitted on inerted vessels, the authors agreed fundamentally, but differed on whether the third system should be fixed or portable. In passing they had to take Mr. McDaniel to task for devaluing the part played by the fire main to the level of "only cooling". They had on record a case where tanks were ignited in an electric storm on a non-inerted tanker in the ballast condition. By using a spray nozzle on the fire hose it was possible for the ship's staff to extinguish the flames and shut the hatch lids.

To clarify their position on foam, the authors said that their company supplied four sets of portable foam making branch pipes to each ship. Generically, these were fire extinguishers, but they should not be confused with those fitted to combat local accommodation fires. Each foam-making branch pipe could deliver about 1000 gal/min of foam using about 5 gal/min of foam concentrate per 100 gal/min of water from the fire main. One set of equipment was erected forward and aft of the manifold before loading, discharging, tank washing or ballasting, and sufficient foam making compound for 20 minutes use was placed nearby. Two sets were held in reserve. The jet throw was about 60 ft and the length of hose usually employed was also 60 ft. 400 gallons of foam-making compound were supplied in addition to another 250 gallons used for the weekly practices. 200 gallons of foam concentrate could supply 20 minutes foam at 2000 gal/min, leaving 200 gallons of foam concentrate in reserve (excluding the quantity set aside for practice). The foam-making solution was manufactured by the induction process, and the expansion ratio of this solution (not concentrate) was about ten to one.

To be preventive did not preclude the ability to extinguish. For example, the inert gas system could be used solely as an extinguisher of tank fires, and in this sense fulfilled the requirements of the quoted fire extinguishing regulations. Naturally, tank fires and explosions were best prevented, and the inert gas system was a practical means of accomplishing this objective when other *extinguishing* systems would be inapplicable for technical or economic reasons in a preventive role.

The authors had carefully reconsidered the five deficiencies of alternative extinguishing systems, and considered that a *fixed* foam system was deficient on every stated count. They entirely agreed that an effective extinguishing system was necessary in addition to the inert gas system for deck fires. They trusted the additional information given on the *portable* foam making branch pipes would show that adequate foam making equipment was available on their vessels. They considered that a preventive measure should be encouraged by the assigning authorities, and, as had been suggested by Mr. Hyde, the deletion of the *fixed* foam system on inerted vessels would provide a significant financial encouragement. The primary requirement, the authors would submit, was the prevention of fire and explosion: to make extinguishing the primary requirement was illogical.

In reply to Mr. Tani, the authors presumed that he referred to the tests carried out on the Japanese built 215 000 dwt tankers. The diagrammatic arrangement given in Fig. 2 correctly showed the purge pipes at the after end of each tank. Each purge pipe was at the opposite end of the tank to the gas inlet. These purge pipes came to within 450 mm of the tank bottom. They were now raising this figure to 900 mm for large vessels with long tanks to avoid chokage of the inlets when there was a large trim. Purge pipes in the aftermost tanks were now placed at the forward end of these tanks to avoid the possibility of gases and entrained liquids going near the accommodation.

Purging tests had been carried out over a wide range of tank sizes, the largest of which were on the 215 000 ton vessels. The tanks of these vessels were 60 m in length with a transverse wash bulkhead at the mid-length. Large transverses were fitted, unsupported by a centre girder. The transverse wash bulkheads were substantially constructed, but proved to have little influence on the distribution of the gas flow to the *single* purge pipe fitted in each tank.

As the authors' company only fitted one purge pipe per tank as a matter of policy and with satisfactory results, the question of gas changes required for individual sections of large tanks did not arise. Indeed, it could be said that this was the whole dilemma of fitting two or more purge pipes, for it would be difficult to prevent preferential flow to one or other of these pipes. Certainly, there was more room for error when more than one purge pipe was fitted, and the failure to open one of them could cause a whole section of a tank to be poorly inerted.

If a wash bulkhead was designed to support the reactions of large bottom and side girders, attention had to be paid to the gas distribution at the design stage, because the area perforated in these bulkheads was very limited. The lightening holes had to be carefully arranged to avoid gas pocketing on the purge pipe side of the wash bulkhead.

The purge pipe diameter was selected to give a reasonable compromise between high gas velocity and low pressure drop. The purge pipe outlet was a minimum of 3 ft above the upper deck, but was sometimes increased where exessive shear existed on the upper deck. A gas velocity of 20 m/s when purging three individual tanks at a time should give a reasonable pressure drop and sufficient outlet velocity. If sufficient pressure was available at the branches of No. 1 across, a maximum gas velocity of 40 m/s could be used.

Inert gas as derived from flue gases was primarily an asphyxiant and had a characteristic pungent smell. The gas concentrations about the decks were well within safe values, but precautions should be taken to avoid inhaling the gas directly from tank openings. During tank cleaning with portable machines the pressure of the inert gas system could be reduced. To reduce further the efflux of inert gas during tank cleaning, the hose saddles could be muffed. Apart from tank cleaning, the arrangement of purge pipes should be such as to avoid accumulation of gases around the accommodation and pump room, and particularly in way of vent inlets.

In reply to Mr. Hyde who wanted to know more about the cost in terms of fuel consumption when the boilers needed to be artificially loaded the authors said that on steamships this was a very rare operation and the increase in fuel consumption was practically negligible. On motor ships, it was sometimes necessary to operate an additional cargo pump during tank washing to give sufficient boiler load for a high quality flue gas. This required about six tons of fuel per day while tank washing. These quantities were significant in a product carrier, and the frequencies of these operations on this type of vessel could well require an extra 130 tons per year of oil fuel. Modifications to the air registers and improved combustion control had lessened the need for the operation of an additional pump during tank cleaning. The type of burner equipment mentioned by Mr. Watson should eliminate the use of the additional pump altogether.

From the environmental point of view, Mr. Hyde suggested that tankers should be fitted with an inert gas system to provide maximum safety. They had not previously considered pollution prevention to be a particular indirect advantage of the inert gas system, but this could be a more real anti-pollution measure than the pollution caused by the scrubber effluent.

Mr. Hyde's assessment of the attitudes of certain shipowners towards the cost of safety led logically to the forcing of the reluctant owner into adopting suitable safety measures by legislation. Their experience showed that the inert gas system required time to be brought into a company's operating norm, and they would not welcome legislation requiring the instant fitting of inert gas systems to all tankers lest this brought the system into disrepute by excessive numbers of maloperations by personnel unfamiliar with the system.

Mr. Hyde's shrewd comments had been a source of strength in the past within BP during the development of inert gas system and the authors took this opportunity of expressing their gratitude.

In reply to Mr. Ferguson the authors wrote that the fitting of separate purge pipes allowed the purging of any combination of tanks without danger of recirculation between pairs of tanks. It avoided the complications that could result when the cargo suction lines were used for this purpose, as the suction lines had to be free of liquids before purging could commence by this method. The use of purge pipes allowed the tank atmosphere to be corrected simply and quickly if any maloperation occurred during discharge of cargo.

The desirability of reducing the hydrocarbons below a certain level (line AB, Fig. 10) in order to prevent the diluted gases passing through the flammability envelope had been brought out fully in the text. An important advantage of fitting a purge pipe was that it allowed the displacement of the gases in the tank when hydrocarbon gases were present. This process was up to three times quicker than the mixing process, which more frequently occurred if the gas was supplied by the cargo suction piping (see also reply to Mr. Hosie).

The principal disadvantages of individual purge pipes were cost and weight. In addition the gases expelled from these pipes were undesirable about the deck. The authors had discussed the design and arrangement of purge pipes in their reply to Mr. Tani, but would mention that a new cargo system had been developed in which the drop lines were used as purge pipes. Each tank was fitted with a drop line, and the purged gases were exhausted from the manifold. The use of drop lines as purge pipes offset to a large extent the cost and weight disadvantages of individual purge pipes. If this type of system was not practicable for any reason then they strongly recommended that individual purge pipes be retained.

In reply to Commander Wood the authors said they still had some difficulties with the fans and particularly with fan inlet cones and casings. They welcomed new materials which could be shown to be successfully applied in these conditions, but it had to be remembered that it was because the fan runner could not be kept clean, and therefore in balance, that overhung impellers were particularly unsatisfactory.

They doubted whether the pH value of the water entrained in the inert gas was as low as 2. When carry-over occurred, it was due to excessive water supply, the drowning of the demister, or a fault in the scrubber design allowing insufficient disengagement space above the water in the top stage. The pH of the effluent decreases from the top to the bottom of the scrubber and for this reason the pH of the carry-over had to be considerably greater than the mean values of 2·4 to 2·7 quoted in the paper. If water was carried over, it was more than likely that it had failed to partake in any scrubbing action. When the scrubbing tower was working normally, the heating of the gases in the fan should reduce the humidity.

The authors' company naturally required the best scrubbing towers available, provided that improvements in efficiency were not outweighed by increased complexity, excessive fan motor power or weight. The figures given in Table 12 showed that high efficiencies in terms of SO_2 removal were easily obtainable even with bubble tray scrubbers. Their requirements were clearly specified in the paper and they were considered realistic. To obtain the cleanest inert gas, i.e. 100 per cent SO_2 removal—nil solids and low humidity—it would be necessary to add electrostatic precipitators, dehumidification and possibly an alkali injection system (see Ref. 2). In their view, the increased complexity, maintenance and capital costs of these additions were not recovered, and this ruled them out for all but the most sophisticated products.

They had compared various types of scrubbing tower on the full scale, and would make more comparisons if the time and expense could be justified. If an individual supplier wished to make a full evaluation of his equipment, including the evaluation of the solids burden, at his own expense, shipboard facilities could be provided.

Their own scrubbing tower was certainly not the cheapest available and it might not be the most efficient, but it had proved to be adequate for the service intended.

Mr. Victory had pointed out that a figure of 240 minutes to inert the largest space of an oil tanker would be considered inadequate if the system were installed purely as a smothering system. In reply the authors said that as flow rates of inert gas systems for oil tankers were related to the cargo discharge rate, it was unlikely that the time for one atmospheric change would approach 240 minutes. Nevertheless, the point made by the authors was considered valid, in that the inert gas system as fitted to BP ships easily fulfilled any requirements for a smothering system, even though it was primarily a preventive measure. The hazard of static electricity associated with pure CO_2 extinguishing systems did not of course apply to the low gas velocities of the type of inert gas system considered in this paper. The authors were sure that Mr. Victory did not intend this to be read into his remarks, but they felt it important to clarify the point.

The authors agreed that the purged vapours should be released as far forward from the accommodation as was practicable, but no flammable concentrations should persist about the deck due to the high exit velocity. Rather than fit a deck extension, the authors preferred to fit the purge pipes at the forward end of the after tanks.

They had recently suffered from the carry-over of loose oil during purging on two of their 200 000 ton tankers. Three solutions to the problem of liquid carry-over have been satisfactory. These were:

i) increasing the height of the purge pipe inlet to 900 mm above the tank bottom;
ii) placing the purge pipes at the forward end of all tanks, except in the forward most tanks;
iii) purging through open ended cargo drop lines.

The authors had already discussed solution (iii) in their replies to Messrs. Ferguson and Tani, but it could only have a limited application unless drop lines were fitted to each cargo tank. Solution (ii) was preferable when other cargo systems were employed, particularly in the aftermost tanks. Solution (i) was also acceptable, but they would now advise that the purge pipes in the aftermost tanks be fitted at the forward end of these tanks.

The IOTTSG gave recommendations concerning the position of vent outlets taking into account the height of the vent and the exit velocity of the gases. The main problem was the position and height of the main vapour mast rather than the purge pipes. The hydrocarbon gas concentration used in the IOTTSG recommendations was 50 per cent by volume; it would be seen that such a figure was unlikely to occur when purging gases from empty tanks.

It would be an advantage to be able to displace the air from a tank by injecting the inert gas at the bottom, especially in product carriers. As their suction lines were drained prior to loading it was possible to re-inert by displacement even with the BP system. The mode of operation would make use of the cargo suction lines and the pressure of gas in an adjacent tank. They felt sure that the ship's staff would prefer to use the purge pipes in the conventional manner to avoid this complication. A separate connexion to the cargo suction lines was in fact fitted to *British Skill*, but the facility was never used.

Mr. Victory had suggested that one reason for the oft quoted comment that the inert gas system can give a "false sense of security" was the possible lack of communication between deck and engineer officers regarding the quality of the inert gas during cargo discharge. Even in the best companies communications between deck and engine sides had been known to break down, but they did not believe this was the root cause of a false sense of security. This was the result of indifferent discipline and a lack of routine. The rarity of explosions and fires and the importance of the immediate tasks could lead to over familiarity and the devaluing of all safety matters. Dr. Sutton had emphasised this point in his contribution, and the measures taken to avoid a false sense of security were summarized in the concluding remarks of the present paper. There was also a danger that an over-complicated system could throw an unacceptable work load on to the ship's staff who might be tempted to take short cuts. Consequently the authors did not consider an additional record would contribute positively, but they agreed that an indication of the percentage O_2 or percentage CO_2 downstream of the fan would be valuable. The sensing point mentioned in the final paragraph of section 11 was used for check testing. On the latest installations a reading would be relayed to the cargo control room. They did not think it was necessary to have readings recorded at the fan discharge particularly in view of the indifferent performance of recorders on board ships and the desirability of reducing instrumentation to a practical minimum. This was a good example of an additional "safeguard", however well intentioned, defeating the object of simplicity. The authors regarded simplicity itself as an additional safeguard. They agreed that the cost of a recorder would be insignificant, but were against what appeared to be a valid point on the grounds of complication. They felt sure that Mr. Victory, as a practical marine engineer, would sympathise with the need to reduce the paper inflation to a reasonable "norm".

Mr. Frisk, who had been responsible for the fitting of the inert gas systems to the BP product carriers built in Sweden had stressed the need for simplifying the inert gas systems. Replying the authors said that on product carriers there was a necessary complication due to the requirement for segregating vapours between grades. The product carrier system advocated in this paper represented a considerable simplification on previous designs, one of which had an extra deck line and twice the number of valves as their proposal.

On crude oil vessels, the absence of all tank vapour valves and the fitting of one vapour main produced a deck system which was difficult to simplify further. The deletion of purge pipes or their equivalent would simplify the system but complicate the operation (see reply to Mr. Victory). The deletion of the standby fan would again "simplify" the system, but would reduce the high standard of reliability required. The authors agreed with Mr. Frisk that many problems had been reduced to the proper selection of materials. It would appear wrote the authors, that their main problem with respect to simplification was to prevent increased complication arising from desirable, but not strictly essential, system safeguards.

In reply to Mr. Wilse the authors said they had quoted four criteria for system capability, but it would be noted that a degree of flexibility was permissible. They had accepted system capacities as low as 1·22 times the cargo discharge rate.

The soot blower interlock was a desirable safeguard, but the electrical circuit had to be arranged so that it failed "safe". Thus, failure of the interlock should not prevent the operation of the inert gas system. This interlock was not strictly a safety feature, as it was really there to reduce maintenance due to excessive soot deposits in the valves and lines to the scrubbing tower. They therefore felt that this interlock should be a "recommended" rather than a "mandatory" fitting. The explosions on the OBO carriers brought into focus the dangers that existed outside the tank cleaning period. It also emphasised the potential value of a preventive system that was effective throughout the whole cycle of operations.

The type of venting arrangements sometimes employed on OBO carriers were considered undesirable if a main line was placed in such a position that liquids could accumulate. The type of system suitable for an OBO ship was dependent upon the type of hatch cover and ore handling arrangements. It could be that sections of the vapour piping could be made portable between hatches to allow the inert gas to be delivered through the top of the hatch. This would give self draining lines and avoid the suction pressure that could occur on the tank structure if the gas inlet was choked during the initial stages of cargo or ballast discharge.

In reply to Dr. Sutton the authors said that his work on all aspects of tanker safety was well known to the industry. The authors were grateful for his kind remarks, but wanted to make it clear that Dr. Sutton himself supplied much of the energy and motivation required to ensure the proper handling of such a long term project.

They could only endorse Dr. Sutton's comments regarding the importance of providing all working personnel with a full understanding of the system, and the need for continuing co-ordination between Head Office and ship personnel.

The authors said they had attempted to be objective in their examination of the inert gas system and this had led to a thorough examination of all problems or objections. They heartily agreed that apart from the many in Head Office and at the oil terminals who had helped, the most striking feature was the enthusiastic co-operation from the fleet personnel. Without this co-operation from the fleet, the project would have finished shortly after it commenced. Although there had been difficulties in the operation and maintenance of this system, these had in no way prevented the complete acceptance of the system by fleet personnel.

They considered that the contributions made to their paper had enhanced its value and they were grateful to all those who had made them.

REFERENCES

11) Beer, W. J. "Analysis of World Merchant Ship Losses". *Trans. RINA*, Vol. III, 1969, p. 97.

Conversion Table

Imperial Units		Recommended Units
1 in	=	25·4 mm
1 in w.g.	=	25·4 mm w.g.
1 ft	=	3·048 m
1°F	=	9/5° C
1 oz	=	1/0·035 mg
1 lb	=	0·4536 kg
1 ton	=	1·016 tonne
1 gal	=	4·546 litres