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OILY WATER SEPARATORS AND OIL CONTENT MONITORS — REVIEW OF CURRENT EQUIPMENT

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Detailed are the results of a study undertaken during 1971/72 to determine the current position of oily water separators with particular emphasis on capacity, efficiency and availability, when considered for use in the marine environment. Five gravity and one coalescing-type separator were specifically designed for use by the marine industry at the time of evaluation. However, all types of equipment known to be generally available for the separation of oil and water were investigated, performance levels assessed, and in the majority of cases, equivalent costs quoted. A parallel investigation was undertaken of oil monitoring meters.

INTRODUCTION

Mankind's recent interest in the preservation of his environment has led to a renewed and somewhat profound interest in ecology generally, and the condition of the world's oceans specifically.

Until comparatively recently, the industrially orientated communities have been largely separated from natural energy resources resulting in the design, construction and operation of VLCC and similar massive transport. The normal operation of these vessels involves intimacy of water and oil either by design, i.e. tank washing or by fault-bilge contamination, which if not controlled could result in substantial subsequent contamination of the sea due to expedient dumping.

Recognizing these facts and anticipating the requirements of deliberations at IMCO which led to the 1973 International Convention for the Prevention of Pollution from Ships, the Chamber of Shipping, presently the General Council of British Shipping commissioned the Marine Industries Centre of the University of Newcastle upon Tyne with the problem of evaluating the position of oily water separators from the standpoint of efficiency, applicability, reliability and most importantly their availability at an economic cost.

It is predominantly the results of that particular study, which was undertaken during 1971/72, which are presented here. The original objectives of the programme were designated as follows:

1) to provide comprehensive information of oil/water separating equipment presently in use and currently available in the production, prototype, research or basic embryo stage;
2) to determine the relationship between performance, cost, magnitude of installation and viability of application to ships of the merchant marine;
3) to obtain a realistic specification for oil removal from water considering economics of operation, production and engineering capability;
4) to obtain detailed information relating to performance and availability of tamper proof, maintenance-free monitoring equipment;
5) to determine a specification for anticipated accuracy of monitoring equipment and to briefly evaluate methods of achieving the desired aims.

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Pollution of the sea by oil is, for the most part, not deliberate and the main causes may be summarized as follows:

i) collision or grounding of a vessel at sea causing escape of oil from cargo and fuel tanks;
ii) discharge of tank washings, etc, directly overboard without any form of prior treatment;
iii) discharge overboard of oil-contaminated ballast water from double-bottom fuel tanks;
iv) discharge overboard of tanker ballast carried in dirty tanks;
v) discharge of oil contaminated bilge water from machinery spaces;
vi) discharge of oily sludge and wash water as accumulated from self-cleaning fuel oil purifiers;
vii) accidental spillage during loading, discharging or bunkering;
viii) fracture of welds in bulkheads between cargo and clean ballast tanks.

Cause i) is outside the scope of this paper since such mishaps to a vessel are, in most cases, unexpected and there is a minimum of time available to take any form of evasive action to prevent oil entering the sea. In such situations in recent years, those responsible for dealing with major oil spills have resorted to the use of detergents, flocculents, oil-spill booms, etc, with varying degrees of success. Considerable research has been carried out in Great Britain following the *Torrey Canyon* disaster.

One special aspect of pollution caused by grounding is the potential hazard presented by container ships. These vessels originally were equipped in some instances with container-handling equipment, but more recently all cargo handling has been delegated to shore-mounted cranes. It has thus become impossible for a containership to readily lighten itself by jettisoning cargo in the event of grounding; the crew must, therefore, resort to pumping ballast and fuel oil overboard. This constitutes deliberate, if unavoidable, pollution and obviously some consideration of the special problems of container ships must be made in future legislation.

When oil is discharged into the sea, physical changes in its structure take place and some brief notes on its fate and effects upon marine life are relevant in the determination of permissible levels of oil content of overboard discharges.

In general, crude oil does not present a major direct toxic hazard since the toxic components of crude oil are also highly volatile and rapidly evaporate. While the residual toxicity that remains is so diluted by sea water that it has a negligible effect, it is possible that seabed reactions of sunken oil residues can produce toxic components. It has been established that some of the components used for dispersing oil slicks are toxic and cause serious harm to flora and fauna of coastal waters while the dispersed oil has a greater toxic effect than undispersed crude oil. Long-term health hazards of continued oil pollution are unknown and subject to debate. It seems wisest to err on the side of caution when considering this aspect of pollution. The most alarming factor seems to be that hydrocarbons may be concentrated in marine food chains and reach sufficiently high levels in marine products so as to render say, fish, unpalatable or even unsafe for human consumption. There is reported evidence of cancerous growths on food-producing fish caused by oil pollution. Clark[1] has suggested that because oil is now discharged over a greater area and in a finely divided state, it may present a greater hazard than if it were concentrated.

When oil is discharged in bulk into the sea, it forms a thick layer from which volatiles evaporate and some light fractions dissolve in the sea water. As the layer spreads, further evaporation takes place (fairly rapidly) until only non-volatiles are left. These non-volatiles may form water in oil emulsions which are very stable or they may form oil in water emulsions which may be:

a) broken down by bacterial action;
b) absorbed by plankton;
c) distributed in infinitesimal concentrations.

Kluss[2] in a paper to the 1968 International Petroleum Conference at Brighton, gave figures which indicated that the contents of the slop tank, when discharged into the wake of an 80 000 dwt tanker would be completely oxidated within four days if the sea temperature were 25°C. This paper used the work of Moss[3] and Zobell[4] to justify these figures which, it must be emphasized, only refer to finely divided oil. Kluss did claim, however, that the turbulence of a ship's wake is sufficient to produce the required degree of dispersal. From the evidence of U.K. beaches, it is difficult to accept his conclusions in their entirety.

Accepting that biological action is effective in degrading oil, it should be noted that bio-degradation is a function of water temperature, the process being slower in temperate waters. Hence oil discharged by vessels in Northern European waters stands some chance of reaching the shore before bio-degradation is complete. Areas which are particularly susceptible to lasting damage if polluted by oil are the Arctic regions.[5] Because of the temperature bio-degradation is very slow and, the consequences of an oil spill are likely to be more persistent. Furthermore, Arctic marine invertebrates, at the most, produce one crop of young each year, are slow growing and often live to a great age. Dispersive phases are rare among Arctic marine invertebrates so, overall, a pollution accident would eliminate not only the adults but also the young they breed. Replacement from adjacent areas would be slow because of the lack of mobile phases in the life history of most species and the re-establishment of a population with a balanced age structure might take many decades.

When considering legislation regarding oil pollution it may be advisable to consider the Arctic zones as areas requiring separate and more rigid attention. In this context, regulations relative to pollution in Arctic waters are already enforced by the Canadian Government.

QUANTITIES OF OIL AND WATER UNDER CONSIDERATION

Bilges

The quantities of bilge water to be pumped from a ship varies considerably from vessel to vessel. The type of stern-tube bearing fitted, i.e., water-lubricated or oil-lubricated, has a major influence on the amount of bilge water. It is to be expected that a steam ship is likely to have more water deposited in its bilges than a motor ship and the degree of general maintenance plays an important part. It may be expected that automated engine rooms, releasing engineers to perform day work duties would lead to increased maintenance and, therefore, less bilge water. However, it is the opinion of some superintendent engineers that small items such as leaking glands tend to be neglected now that engineers are not constantly making rounds of the engine room. Figures taken from a Shell Research Limited Report[6] show that a 38 000 dwt tanker required about eleven tonnes of general bilge water to be pumped as well as about 16 tonnes of water from the after well. About three tonnes a day of evaporator blowdown has to be added to these figures. Although by separating the after well from the other bilge wells by welding a dam across the tank top would ensure that the after well water was oil free, the additional piping need not prove to be a justifiable expense. Therefore, a total of between 20 to 40 tonnes a day is assumed for water-lubricated stern-tube gear.

Figures quoted for an older motor tanker (since scrapped) show up to 18 tonnes a day water accumulation plus 35 tonnes a day stern-gland leakdage. In both these tankers the indication was that less than nine litres of oil entered the bilges per day.

Forecasting figures on a basis of data supplied for only two ships can lead to inaccuracies, however, bearing this in mind it would appear that, for a ship fitted with an oil-lubricated stern-tube bearing a design so as to prevent oil contamination of the after well, about 20 tonnes of bilge water containing up to two gallons of oil would need to be handled daily.

Ballast

The majority of ballast water handled obviously results from tankers and the three references[2, 3, 7] give specific figures as to discharge rates and pollution levels.

Ballast quantities can be derived for cargo ships and it may be assumed that they will have a similar level of pollution potential exhibited by the dirty ballast discharge of a tanker.

The worst case that a cargo ship is likely to encounter is when it has to ballast fuel tanks to take up all the space caused by burnt-up fuel. In this unlikely situation 800 tonnes of oiled ballast may have to be discharged at sea.

Passenger liners have ballast problems which are unique in that they may often have to de-ballast fuel tanks at about 200 tonnes an hour within harbour waters.

As far as tankers are concerned, Moss[3] has indicated that a tanker not using load-on-top techniques discharge about 0·3 per cent of the cargo during tank washing while Holdsworth's[7] figures give about 0·2 per cent, i.e., for very large crude carriers (VLCC) 400 tonnes of oil could be discharged if washings are ejected directly overboard.

In the same paper, Holdsworth lists oil and water quantities pumped during ballasting procedures using the load-on-top techniques. Summarized these are:

90 000 dwt tanker

Total dirty ballast discharge = 14 300 m^3, of which:

1) 10 000 m^3 is considered fairly clean as it is pumped from below the oil layer in ballasted tanks;
2) 4000 m^3 is water decanted from slop tanks containing tank washings;
3) 300 m^3 has a high oil content as it represents water pumped from close to the oil/water interface.

Quoted oil contents of these phases are:

i) 30 ppm;
ii) 100 ppm;
iii) 500 ppm rising to 4000 ppm at cessation of pumping.

200 000 dwt tanker

Total dirty ballast discharged = 55 500 m^3, of which:

a) 50 000 m^3 is fairly clean water decanted from below the oil levels;
b) 5000 m^3 is water decanted from slop tanks;
c) 500 m^3 is high oil content water from close to oil/water interface in the slop tank.

The oil content of these phases are:

1) 30 ppm;
2) 80 ppm;
3) 500 ppm rising to 4000 ppm at cessation of pumping.

OILY WATER SEPARATORS

Existing Types of Separators

In the separation of oil and water mixtures there are four main principles applied to the problem. These are:

a) **the use of a barrier device consisting of a porous membrane inserted in the path of flow of the oil/water mixture. The barrier material is chosen with surface properties such that the continuous phase may pass through while the dispersed phase is retained:**

b) the use of a coalescing device which encourages the formation of large oil droplets from small oil droplets. This device is usually an extended surface upon which the deposits can gather:

c) the use of a filter which will retain the dispersed phase depending upon such properties as droplet size, viscosity, filter pore size, and pressure drop:

d) the use of a gravity separating device which depends upon the density difference between the liquid phases.

Theoretical Considerations in the Operation of Oily Water Separators

Most of the separators studied were of the gravity coalescer type and all coalescers considered, with the exception of the pebble-bed type, operated on the principle of specific gravity differential between oil and water.

The rate of separation developed depends for any particular configuration, upon the diameter of the oil particles involved. Large particles are easily separable from water whereas small particles are encouraged to form larger particles in the coalescing device. The resistance to the movement of the oil particles depends upon the flow regime of the mixture through the separator. For small particles moving under streamline conditions, Stokes' Law may be applied, while Newton's Law is applicable to large particles separating under turbulent conditions[8].

Fig. 1 indicates the general relationship which exists between the velocity of separation and the diameter of the oil particles involved assuming that the fluids under consideration exhibit typical properties. From this it may be seen that for a given travel, small particles of oil would take a considerable time to separate out due to the small intrinsic differential head involved. To reduce the dwell time of the oil in the separator, coalescers are utilized which effectively consist of a number of plates of various configurations situated in close proximity. The effect of imposing this restriction on flow is to force the suspended particles of oil closer together thereby encouraging them to combine thereby creating larger globules which exhibit a more substantial separation potential.

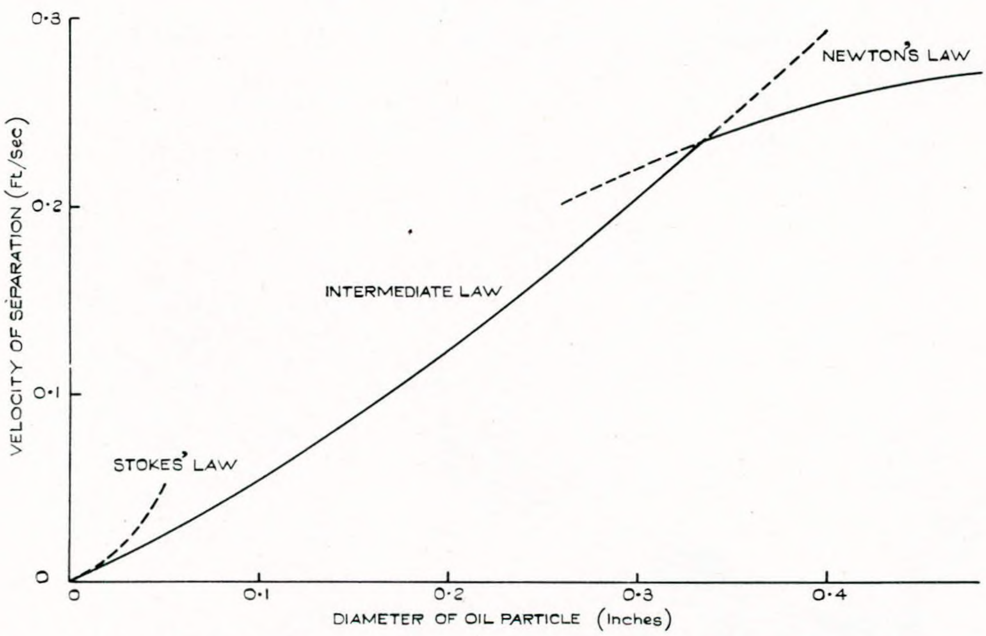

FIG. 1—*The relationship between velocity of separation and diameter of the oil particle.*

Surveys of literature and discussions show that there are numerous systems employed by the process industry for separating different phases in liquid/liquid and liquid/solid systems. Sophisticated systems of flocculation* and aeration† are employed alongside more conventional gravity systems. Generally speaking, the gravity systems ashore are large and allow long dwell periods for the liquids in them. For reasons of economy and space, shipboard separators in use at present use a gravity system in which the flow of mixtures is slowed down and the oil allowed to rise. Plates assist in producing laminar flow and act as coalescing surfaces. One marine unit incorporates a pebble bed coalescer within the system and three companies offer new approaches to the separation of oil and water.

* Flocculation: Flocculents are chemicals which, when added to liquid/liquid mixtures (a) increase in size and (b) rapidly absorb one of the liquid phases. The flocculent with the (unwanted) liquid phase may settle out by gravity or be filtered out of the liquid.

† Aeration: If fine bubbles of air are allowed to rise through a liquid/liquid mixture in which one of the liquids is a finely dispersed phase, the dispersed phase may coalesce on the air bubbles and be carried to the surface of the liquid.

Since the rate of change of specific gravity with respect to temperature is greater for oil than for water, the velocity of separation increases with increase in temperature. Figs 2 and 3 illustrate this effect, and in particular, the increase of rate of separation of small particles with increase in temperature is quite marked.

Fig. 4 shows the temperature/specific gravity relationship for typical fuel oils, fresh water and salt water, and Fig. 5 shows the temperature/viscosity relationship of sea water over a possible range of operating temperatures. The velocity of separation of oil obviously fixes the dwell time of the mixture and hence the size of the separator. It is reasonable to suggest that provided a large enough separator can be fitted, all oil can be removed from an oil and water mixture. For practical reasons, limits must be placed on the size of the separators. The graphs also emphasize the higher separating velocities of large particles and hence coalescing devices to increase particle diameter are incorporated in all separators.

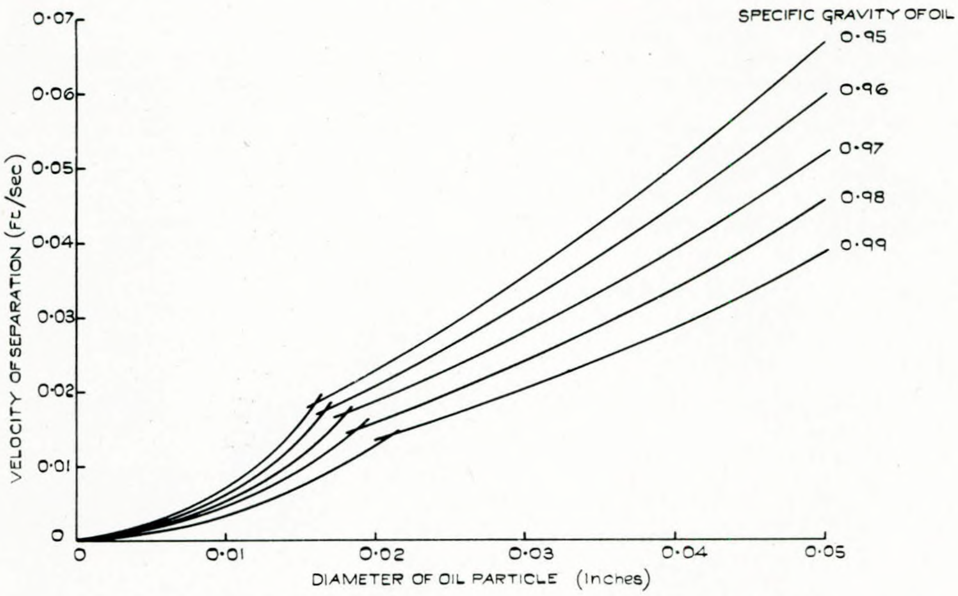

FIG. 2—*The effect of specific gravity of the oil on the velocity of separation.*

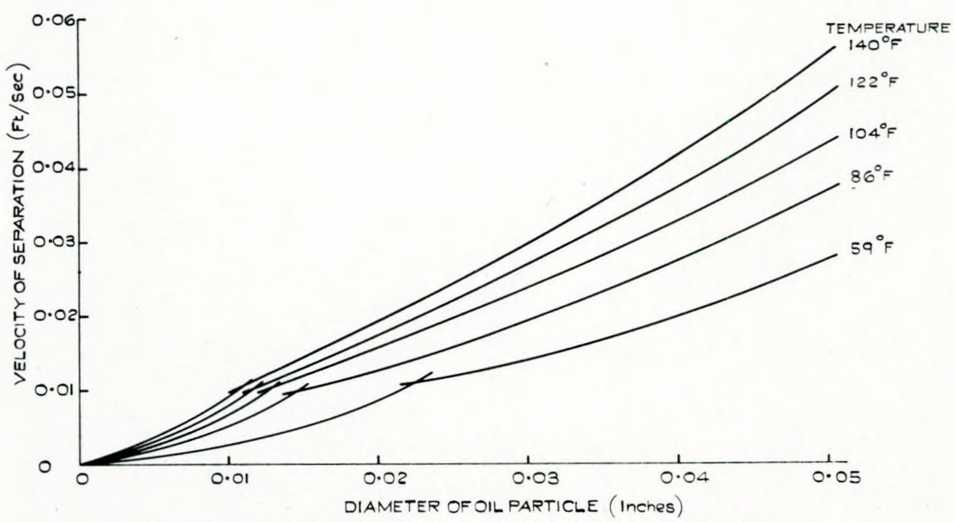

FIG. 3—*The effect of temperature on the velocity of separation.*

The Selection of Oily Water Separators for Bilge and Ballast Duties

It is as well, before comparing specific separators currently available, to note some of the factors which need to be considered when selecting and operating a separator.

Size and Capacity

The size of an oily water separator depends upon the quantity of oil-contaminated water to be treated and the rate of discharge. For bilge duties only, a separator of 10 tonnes an hour may be considered adequate, although some authorities legislate upon size of separator with respect to deadweight tonnage. This criterion seems unduly rigid and reference to horsepower and engine type may be better.

For ballast duties, much higher rates of discharge are involved and for this purpose 100 to 250 tonnes an hour separators are needed. High capacity separators to match de-ballasting at rates of 5000 tonnes an hour are not available, but natural separation within the tanks permit direct overboard discharge of most of the tank contents. The remaining ballast may be discharged at a reduced rate *via* a separator.

Pumps

Pumps associated with oily water separators should be matched to the system thereby eliminating the possibility of exceeding the rated capacity.

Positive displacement pumps of the vane or screw type are an advantage since the tendency to disperse the oil is less than for other pump types[8], but at the moment there is no control over the selection of such pumps.

All pumps should be arranged with a sea water suction for the purpose of initially filling the separator with clean water or washing out at periodic intervals. Where only an oil-fuel transfer pump is connected to the separator, a separate filling line should be fitted.

Provision of Heating

When using a conventional separator of the gravity type, heating coils are used to:

1) reduce the viscosity of the water and thus aid separation;
2) reduce the viscosity of the oil to aid pumping;

3) increase the specific gravity differential and thus aid separation.

There is some debate amongst manufacturers as to the value of 1), 2), and 3) and quite divergent views are held.

Pipe Arrangement

Installation work is considerably simplified if a separator capable of operation in any location, above or below the water line, is fitted. Pipe lines to the discharge pump and the separator inlet should be as straight as possible without sharp bends or reducers. The oil outlet should be designed to prevent siphoning when the separator is not in use.

Manual, Semi-Automatic and Fully Automatic Control

Manually operated separators require the attention of an engineer during the period of operation. If left unattended, particularly when treating large quantities of oil contaminated ballast, it is possible to overload the separator and discharge oil overboard. Separators of this type already fitted to vessels, or where an owner insists on a manually operated unit, should be fitted with semi-automatic control. In the event of the separator becoming overloaded, for reasons already stated, an alarm should be initiated and the supply pump automatically stopped. The pump should not be re-started until the oil within the separator has been evacuated. Where more than one pump is connected to the separator, a selector switch should be incorporated. Standard type automatic-control systems open and close the oil outlet valve as and when required, and no water is discharged overboard during the oil-recovery process.

Fully automatic systems with secondary control, apart from performing the function mentioned in the foregoing paragraph, automatically stop the supply pump should a fault develop within the primary system. The separator should be capable of automatically discharging air which accumulates in large quantities, particularly towards the end of a deballasting cycle as air trapped with the separator can force the recovered oil down to the clean-water outlet. Atmospheric separators, which must be installed above the water line, may be intrinsically automatic when they are full, as no pressure can build up in these separators to push the oil/water interface to too low a level.

Operating Details of Separators Suitable for Shipboard Use

The Aker Separator

The Aker Separator is a two-stage gravity coalescer separator unit and the constructional details are shown in Fig. 6. The first stage is a simple gravity separator when the coarse oil droplets settle out of the mixture and pass direct into the top of the separator unit where the oil collects.

The second stage consists of a series of coalescer plates over which the mixture passes. These plates are tilted so that oil collecting on the underside rises against the prevailing flow of the mixture. The oil is then guided *via* a guide rib into a vertical delivery tube which allows the oil to rise to the collecting dome in the top of the separator.

Solids and heavy sludge could collect in the bottom of the unit over which the clean water must pass prior to discharge from the separator, therefore, unnecessary contamination could take place.

The manufacturers suggest that fouling of the unit could occur if the rated capacity is exceeded and the pump supplying the oily water mixture to the separator should be of the reciprocating type.

The separator can be supplied with fully automatic equipment which will prevent the discharge of excessively contaminated water and heating coils can be supplied for handling oils of very high viscosity. The expected purity of the discharge is not stated, and units are available in standard sizes ranging from 5 to 200 tonnes/h capacity.

The Comyn Separator

The Comyn Separator is essentially a single-stage gravity-coalescer separator, details of which are shown in Fig. 7. The mixture is fed to the coalescing unit which consists of a continuously wound spiral which allows coarse separation to take place immediately, and as the oil collects upon the coalescer plates finer separation takes place.

The separated oil flows upwards to the oil-collecting chamber and the water continues downward where solid particles can settle out and remain before the flow is directed to the clean water discharge.

No specific claims are made with regard to the oil content of the effluent, but type testing indicates that it is always less than 50 ppm.

Automatic operation and heating coils are available as required, as well as a fail-safe supply pump shutdown system.

Capacities are available up to 150 tonnes an hour and for larger capacities it is recommended that the internal parts of

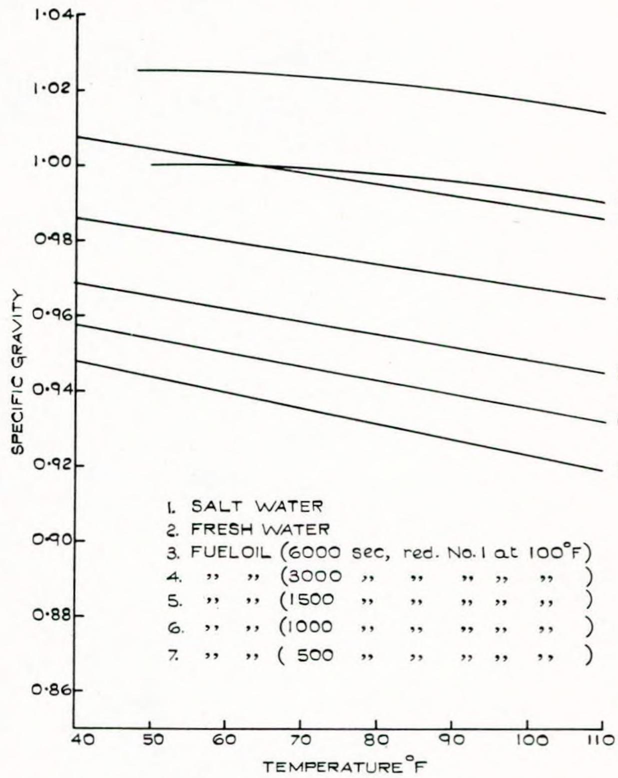

FIG. 4—*The relationship between specific gravity and temperature for typical fuel oil, fresh and salt water.*

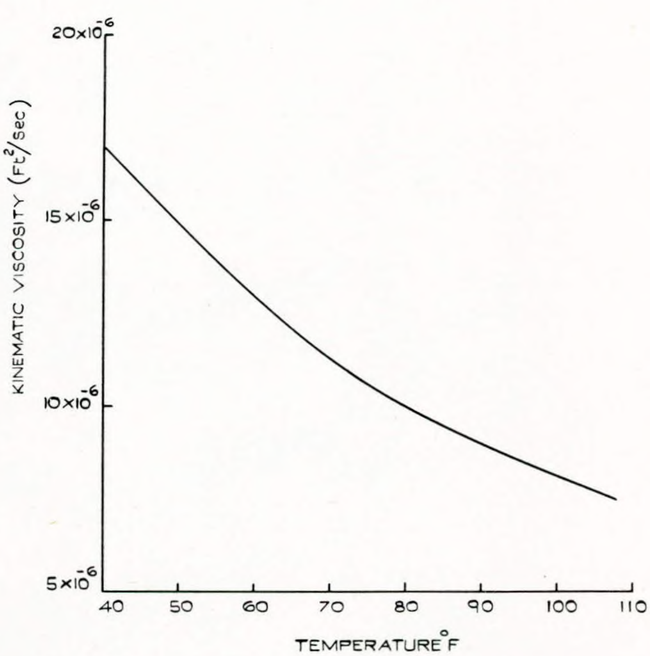

FIG. 5—*The relationship between viscosity and temperature for sea water.*

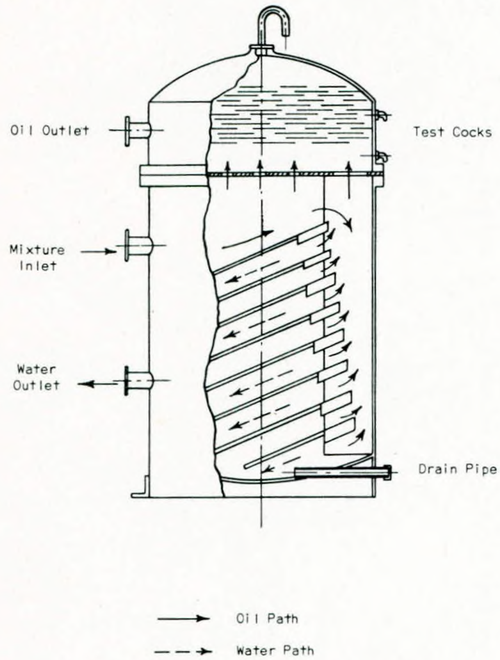

FIG. 6—*The Aker oily water separator.*

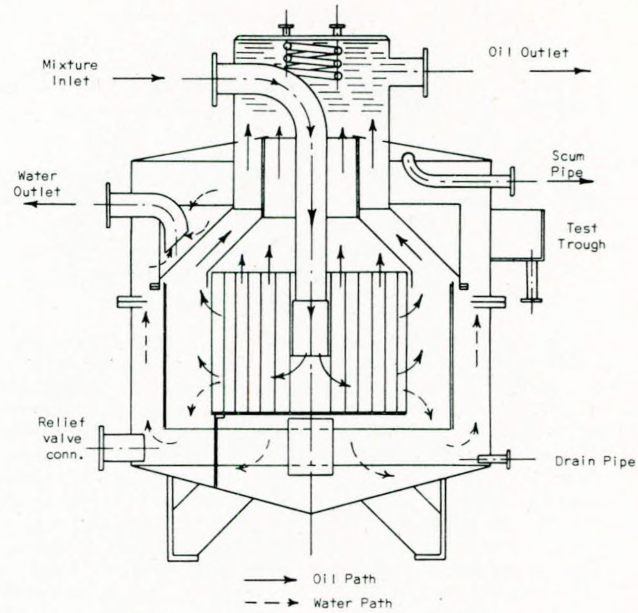

FIG. 7—*The Comyn oily water separator.*

the separator are built into specially constructed compartments of a vessel as shown in Fig. 8, the operation of such a system being the same as that already described.

The Firtop Separator

The Firtop Separator is a two-stage gravity-coalescer separator developed by the Department of Scientific and Industrial Research and was the subject of a technical paper[9] in 1961. Details of the separator are shown in Fig. 9 and consists of the first stage where coarse separation takes place due to gravity. Oil rises and is collected at the top of the separator which is a horizontal, cylindrical unit.

The second stage coalescing device consists of a bed of closely packed gravel with pebble sizes ranging from 0·06 to 0·12 mm. The mixture is passed through the pebble bed and the collected oil rises to the secondary separating zone which also has an oil-collecting chamber.

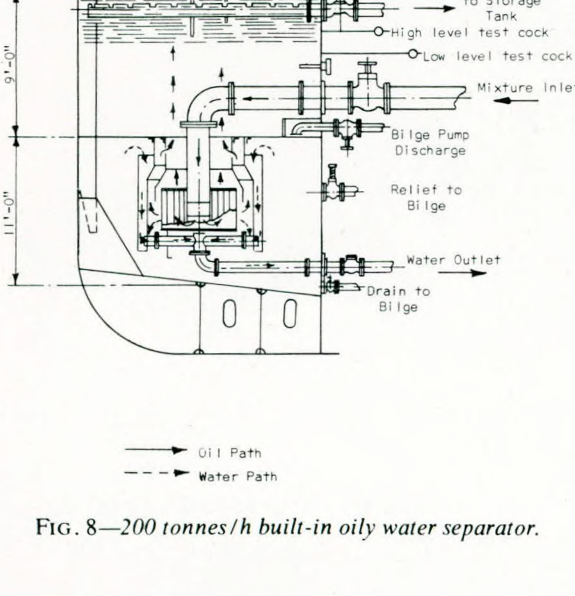

FIG. 8—*200 tonnes/h built-in oily water separator.*

For separators up to 100 tonnes an hour capacity, units are constructed with a single pebble bed coalescer and units of up to 500 tonnes an hour capacity are available with a two tier pebble bed construction.

The units can be supplied as fully automatic or manual and it is claimed that the effluent should contain, on average, less than 10 ppm, but this is dependent on the oil content of the mixture at the inlet to the separator and Ref. [9] suggests an oil content of 6 to 31 ppm.

Because of the pebble bed, this unit tends to be very heavy and its construction may lead to difficulties during cleaning of the internal parts although it is possible to clean the coalescer unit by back flushing through the pebble bed.

The Shell Parallel Plate Interceptor

The Shell Parallel Plate Interceptor shown in Fig. 10 has been developed for use in the process industry and is the type of separator that can be used to receive tanker slops.

Oily water first enters a sand trap where stones, grit and other dense solids fall out. Rags and similar floating debris are caught in a trash rack. The water descends the inlet pipe where a vortex forms, holding floating oil at its core, discouraging emulsification.

Before entering the parallel plate assemblies, the mixture is calmed in a Vee-box and passes through vertical feed slots which produce a uniform flow distribution.

Once the flow is passing through the parallel plate bundles, rising oil particles are caught against the smooth undersides of the plates and flow upwards. Sludge particles usually solids coated with oil, fall on to the upper surface of the plates and flow downwards to drop into the sludge compartment.

The Tilted Plate Separator

The Tilted Plate Separator is shown in Fig. 11. Since it is not a pressurized unit it is not suitable for marine use in its present form although the provision of a suitable pressure vessel seems a fairly simple matter. It is also larger than its marine counterparts for apparently similar duties. This may be due in some measure to the differences in effluent specification adopted by different authorities as well as the shape of the unit. The shape makes for easy maintenance and erection and the provision of standard plate bundles allows economic production of all sizes of unit. Separation is in two stages, primary separation taking place in the inlet area and secondary separation within the plates. The plate bundles are composed of several corrugated plates held together by stiffeners which also constitute gutter ways connecting the

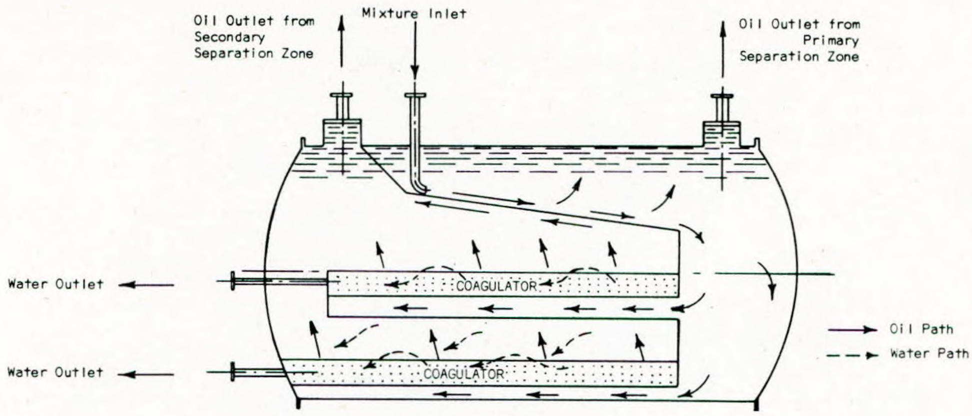

FIG. 9—*The Firtop oily water separator.*

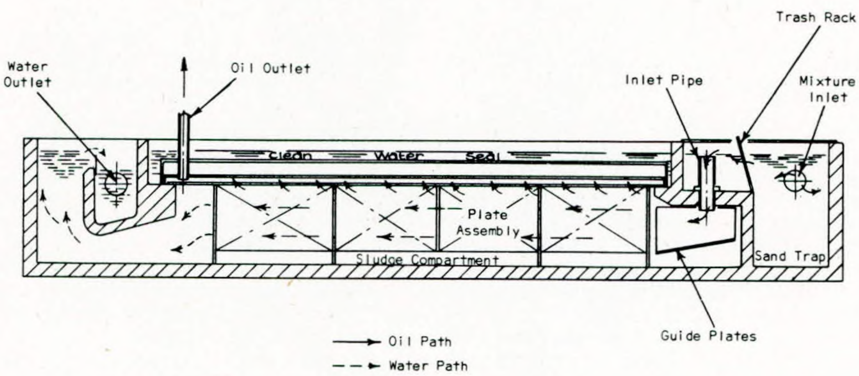

FIG. 10—*The Shell Parallel Plate separator.*

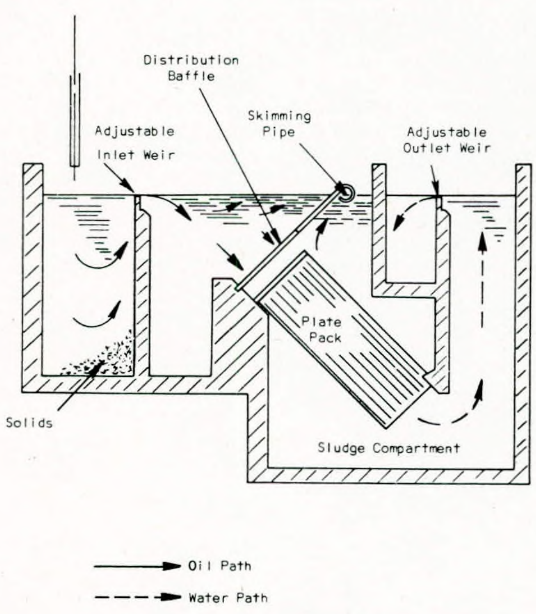

FIG. 11—*The Tilted Plate separator.*

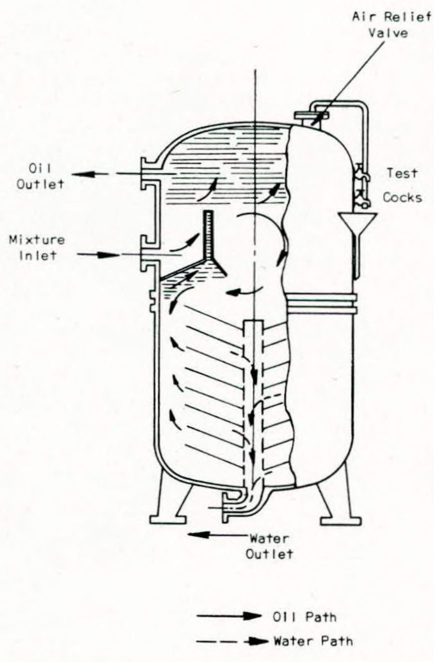

FIG. 12—*The Turbulo oily water separator.*

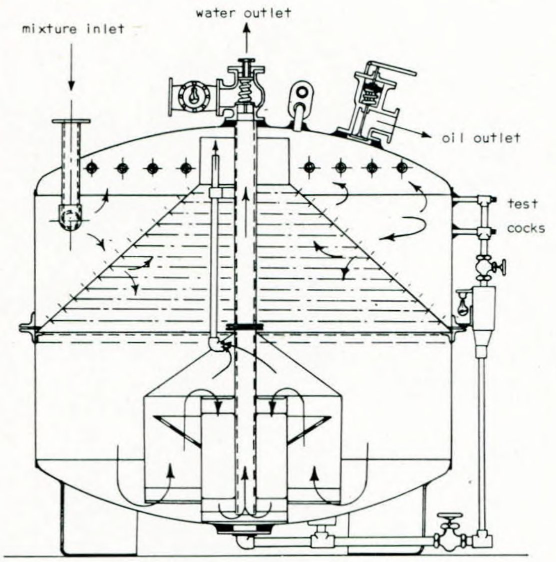

FIG. 13—*The Victor oily water separator.*

apices of the corrugations, the oil rising upwards through the stiffeners without being disturbed by the incoming oil.

The Turbulo Separator

The Turbulo Separator is a gravity-coalescer separator and consists of two chambers. In the primary chamber, coarse separation takes place due to gravity before the mixture is passed through the coalescer which consists of a series of dished plates upon which small globules of oil collect after which the oil is passed upwards through pipes into the oil-accumulation space. It is claimed that the resultant effluent has an oil content of less than 20 ppm and capacities range up to 250 tonnes an hour. It is recommended that this separator should be located below the water line and should only be used with slow-running piston pumps.

The equipment is available with manual or automatic oil discharge control. Automatic control is actuated by capacitance probes which detect the position of the oil/water interface. An undesirable feature of this separator, which is shown in Fig. 12, is that the incoming stream of water is allowed to pass through the layer of separating oil thus re-mixing it with the water below it.

The Victor Separator

The Victor Separator is a gravity-coalescer separator and consists of two chambers as detailed in Fig. 13. In the primary chamber coarse separation takes place due to gravity before the mixture is passed through the coalescer which consists of a perforated, conical baffle.

The flow is split up into small streams and re-distributed over the area of the secondary chamber of the separator where further gravity separation takes place. Oil from the secondary chamber collects with oil from the primary chamber in the top of the separator prior to being drawn off.

Operation of the separator is manual or automatic and capacities are available up to 300 tonnes an hour. The operation of this separator is affected by its location and the water discharge should not be situated at a height exceeding five metres above the separator.

The oil content of the discharge is not stated, but type testing indicates that the level of contamination of the effluent is less than 50 ppm oil.

The Victor Conversion Unit Type Separator

The Victor Conversion Unit Type Separator can be fitted into the tanks of an oil tanker to deal with dirty ballast and tank washings. Two sealed pumps are installed in the tank, one at the bottom to deal with clean water, the other at the top to skim off oil. These are used in combination with a weir and have been successfully used in the floating tank-cleaning installations at Le Havre, Bremerhaven, Lisbon, Skaramanga and Palermo. Fig. 14 shows the system. Capacities are up to 1000 tonnes an hour.

The Butterworth Separator

The Butterworth Separator is a gravity-coalescer separator and consists of three chambers within the outer shell which are formed by conical baffles, apex down, with short entry tubes.

Coarse separation takes place at the inlet from which the mixture is passed to the bottom of the separator and over the first set of baffles. Fins arranged in conjunction with the baffles coalesce the oil particles and oil is collected in the upper regions of this chamber before passing to the oil outlet chamber. Th mixture then passes through another similar set of baffles and fins and the oil collecting chamber is again separately connected to the oil outlet.

The construction of the unit is such that once the weirs are adjusted and the separator full, no extra automatic controls are required to prevent oil flowing out through the water exit in the event of very high feed concentrations. The purity of the discharged water is not stated, but the unit presumably meets the required performance level.

Single units are available with a capacity of up to 300 tonnes an hour and a duplex unit will handle up to 600 tonnes an hour. The type of pump to be used is is not specified and the separator should be installed above sea water level. Fig. 15 shows a section through the unit.

Bilgewater Separator

The Bilgewater Separator is a gravity-coalescer separator which is detailed in Fig. 16 and is a development of the Amsel Settler. The mixture enters the separator and passes through a bundle of horizontal, corrugated plates which are placed vertically at intervals of 10 mm. The oil collects in the apices of the corrugations and the water in the troughs and with the major axis inclined at about 5° to the horizontal, the coalesced oil flows along the corrugated plates into a section of flat vertical plates. Final separation takes place in a cylindrical, vertical end piece from which the separated liquids are withdrawn from the system.

Increased separating efficiency can be obtained by combining two identical separators in series, and shipboard tests on this arrangement have produced effluents containing less than 100 ppm oil. The capacity of the separators tested was very small, one tonne an hour, but future development in this field may take place.

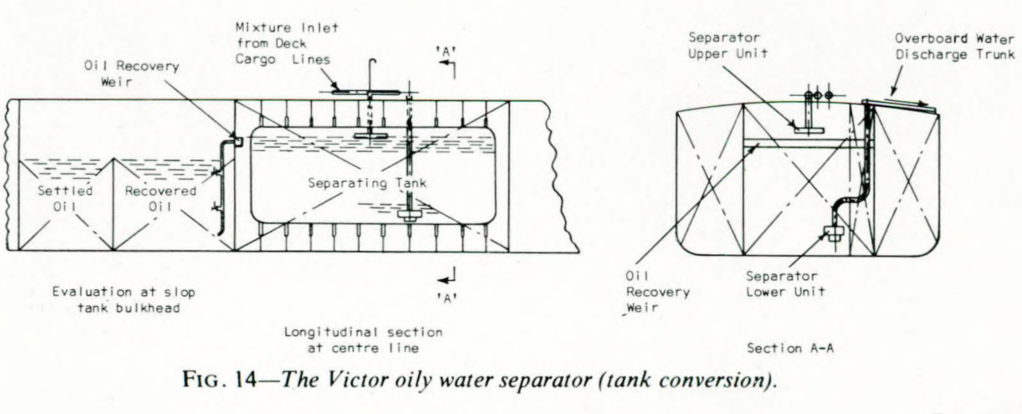

FIG. 14—*The Victor oily water separator (tank conversion).*

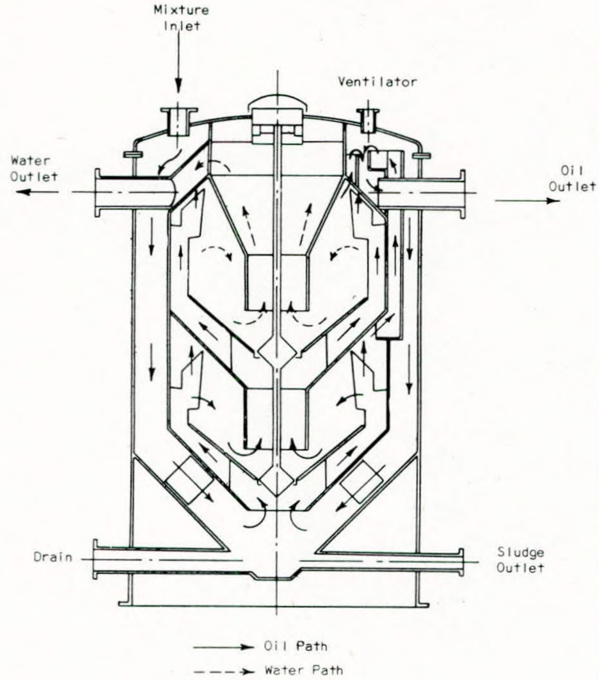

FIG. 15—*The Butterworth oily water separator.*

The Fram/Aker Oil Water Separator

Fram Filters Ltd., manufacture an automatic oily water separator system, developed by the Fram Corporation of the United States of America. This company has obtained the licence to manufacture the Aker oily water separator from Nylands Verksted and this unit is incorporated in a complete system consisting of pumps, pre-conditioners, Fram/Aker separator, emulsion breakers, pipework, valves, fluid analyser and automatic controls.

The mixture is pumped through the pre-conditioner which removes gross solids by using cleanable and replaceable cartridges. The mixture then passes to the Fram/Aker separator which has been previously described, and then to the emulsion breakers which treat the effluent from the separator and use a process of mechanical impingement and preferential wetting to break any remaining emulsion of oil and water. This is carried out by cartridges which can be cleaned and replaced. The systems can be arranged as single, semi-automatic or dual automatic and are shown diagrammatically in Fig. 17 and 18. The dual automatic also includes a backwash holding tank for the back flushing of the idle pre-conditioner and emulsion breaker.

This separating system has been tested in the U.S.A. and has resulted in producing effluents containing less than 15 ppm oil in water.

The Electrolytic Separator

Pollution Technical Services Limited is a major supplier of shore-based sewerage plant and paint separating plant. The oily water separator (see Fig. 19) proposed by this Company depends upon an electrolytic field being applied to the mixture in a settling tank which, it is claimed, increases separation efficiency. The equipment is of large volume since, in addition to settling tanks, holding tanks are also necessary. Because of its large volume, it is not considered suitable for shipboard use.

Discussion

The equipment discussed is made by established marine separator manufacturers and three industrial separator manufacturers, namely Fram, C.J.B. and Pollution Technical Services Limited.

The information received from several U.S. manufacturers has been insufficient for their products to be evaluated. From the data available it seems that U.S. separators work on similar principles to the separators described in this report and should have fairly similar performance levels.

Separators currently used for the treatment of oil/water mixtures fall into two general categories:

i) gravity type;
ii) coagulator type.

The gravity type of separator is the most widely used and this group can be sub-divided into a further three categories:

a) single stage;
b) two stage;
c) three stage.

The multiple-stage separators occupy less space and weigh less than the single-stage separators, but offer no advantage in producing oil-free effluent. In fact, the multiple-stage units offer a distinct disadvantage as the velocity of flow of the mixture through the separator invariably increases when passing from one stage to another resulting in increased turbulence and subsequent continued suspension of small oil globules. The single-stage separators operate at a low mixture flow velocity which allows the separation of smaller oil particles to take place and generally results in a cleaner discharge.

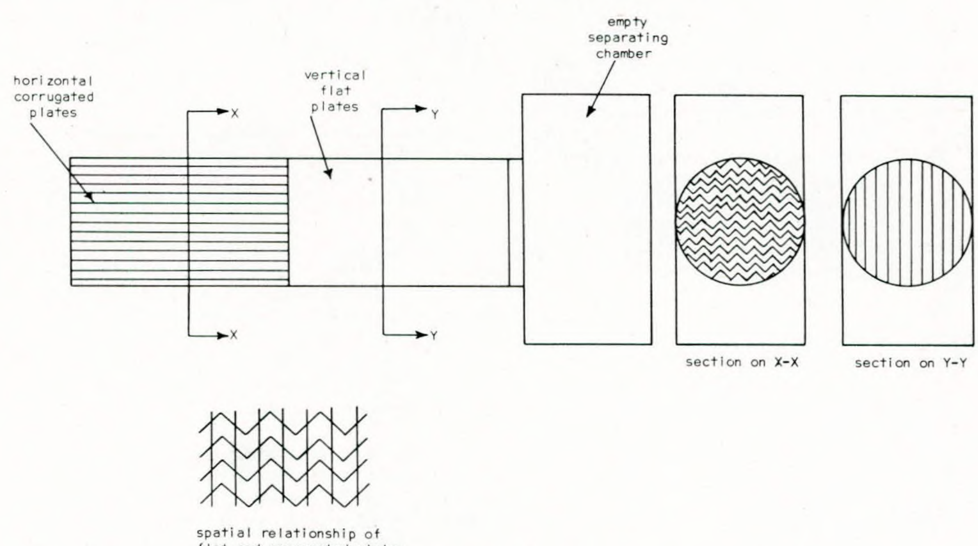

FIG. 16—*The Shell Amsel separator.*

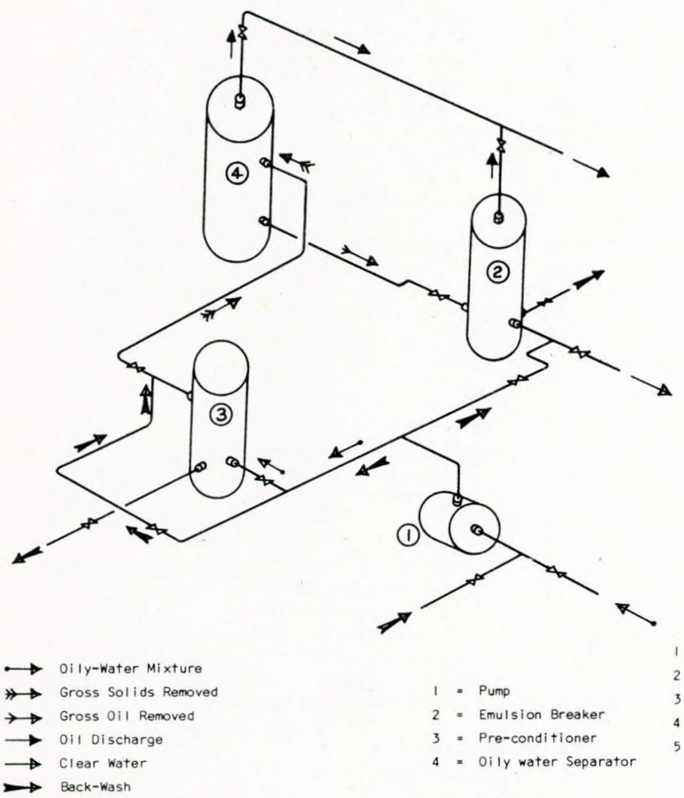

FIG. 17—*Fram/Akers single semi automatic separator system.*

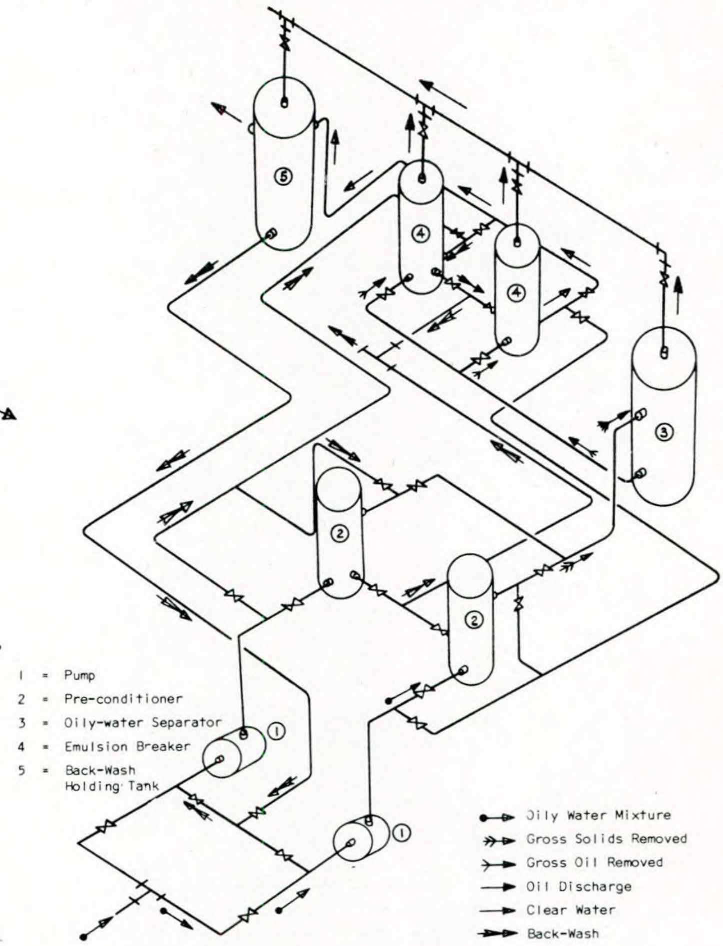

FIG. 18—*Fram /Akers dual automatic separator system.*

All the separators studied, with the exception of one, operate in the turbulent region of flow. Type testing and manufacturers' claims indicate that the present legal limit of 100 ppm in discharges from machinery space bilges is not being exceeded.

The one separator which operates in the laminar region of flow is very much larger than any of the others, but it is claimed that the effluent contains as low as 1·6 to 9·1 ppm oil in water depending on the oil content at the inlet to the separator. This particular separator uses tilted plate packs and its manufacturers are pursuing an active sales policy in the marine industry.

The performance of oily water separators currently used in marine applications, does not vary much between the available types. All are similar in design and physical dimension, therefore similar performance levels can be expected.

The Reynolds number (Re) has been calculated for each separator within each manufacturer's range and comparison is made in Fig. 20 between the available equipment.

In general terms the steeper the curve, owing to the flow being less turbulent, the separator should be more efficient.

For low capacity separators of 10 tonnes an hour, the performance of all separators will be similar as the flow in each case is close to laminar, but in high capacity separators a definite spread indicates the following probable order of separation efficiency based on flow characteristic:

a) Victor*
b) Comyn
c) Firtop†
d) Akers
e) Turbulo
f) Butterworth**

* D.T.I. limitations applied.

† Higher separating efficiency is claimed due to the pebble-bed coagulator.

** Reynolds numbers have been doubled because of counter-flow within the unit and even turbulence at interstage connexions.

Filter Element

The performance of all gravity type separators could be improved by the addition of a filter element as a final stage of treatment. This filter would be a separator unit connected to the separator by a pipework system which would include a by-pass back to the mixture tank as it is unlikely that a filter would cope with water containing a large proportion of oil such as is encountered when approaching the oil/water interface towards the end of a de-ballasting cycle. One manufacturer already makes such an addition for land-based units and claims that the oil content of the effluent is effectively reduced to zero.

Coagulator

Information describing the coagulator type of separator was obtained from two manufacturers and each employed a first stage gravity separator zone. One coagulator was described as a pebble bed and the material of the other was not described at all, apart from being in cartridge form and easily replaceable. The performance of the coagulating separator is, perhaps, nominally better than that of the gravity separator as type testing has produced effluents containing 15 to 25 ppm and 25 to 40 ppm respectively. Reports indicate, however, that the performance of separators at sea deteriorates to such an extent that the effluent contains twice as much oil. The performance level therefore may be taken as 30 to 50 ppm and 50 to 80 ppm respectively.

Reduced Capacity

It has been shown that the performance of separators can be improved by reducing the throughput of contaminated water. Fig. 21 indicates the performance level expected when reducing the capacity of each type. From these performance levels it would appear that the gravity separator is affected by a reduction in capacity, but the performance is much the

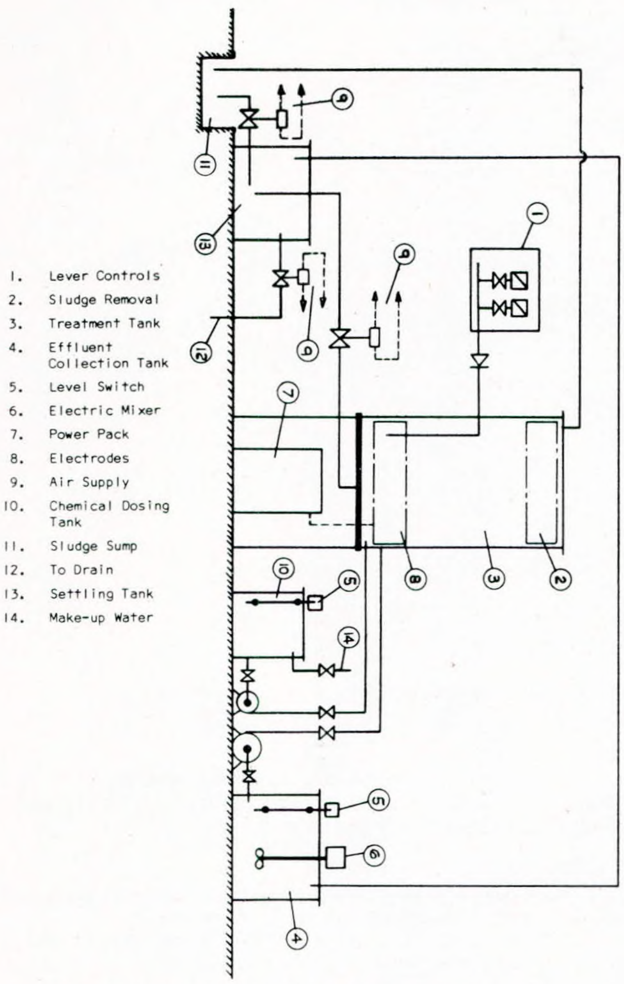

FIG. 19—*Pollution Technical Service electrolysis separator system.*

same when producing effluents containing 25 ppm or less. A typical example of increased performance is indicated by limiting the flow characteristic, i.e., Reynolds number of 2000 in a separator which is normally rated at 110 tonnes an hour and is 8 ft 6 in in diameter.

$$\text{Reynolds number} = \frac{vd}{\text{v}}$$

where v = Velocity ft/sec
d = Diameter ft
v = Kinematic viscosity of sea water
= $16{\cdot}6 \times 10^{-6}$ ft²/sec at 40°F

$$\text{Max } v = \frac{2000 \times 16{\cdot}6 \times 10^{-6}}{8{\cdot}5}$$

$$= 0{\cdot}00391 \text{ ft/sec}$$

$$\text{Max } Q = 0{\cdot}00391 \times \frac{\pi}{4} \times 8{\cdot}5^2$$

$$= 0{\cdot}222 \text{ ft}^3\text{/sec}$$

$$= 22{\cdot}8 \text{ tonnes/h}$$

i.e. the separator must operate at:

$$\frac{22{\cdot}8}{110} \times 100 = 20{\cdot}7 \text{ per cent capacity}$$

which would result in an effluent of approximately 15 ppm oil in water.

Fig. 20 shows that the performance of the Aker Gravity separator around which the Fram/Aker system has been designed is only mediocre, but the addition of pre-conditioners and emulsion breakers results in an effluent containing less than 10 ppm oil in water.

The equipment offered by Pollution Technical Services does not have a very good performance level at 50 ppm oil in the effluent water. Three tanks are required in this system resulting in a large cargo space loss and generally has no advantages over the gravity types in current use.

OIL CONTENT MONITORS

The literature survey carried out for this report showed that there are several basic principles which can be used for the detection of oil in water. These principles are generally the tools of the analytical chemist but some of the less sophisticated methods can be used by persons who are not particularly trained in that field.

There are techniques such as:

1) gas-liquid chromatography;
2) thin-layer chromatography;
3) atomic-absorption spectrophotometry;
4) solvent extraction.

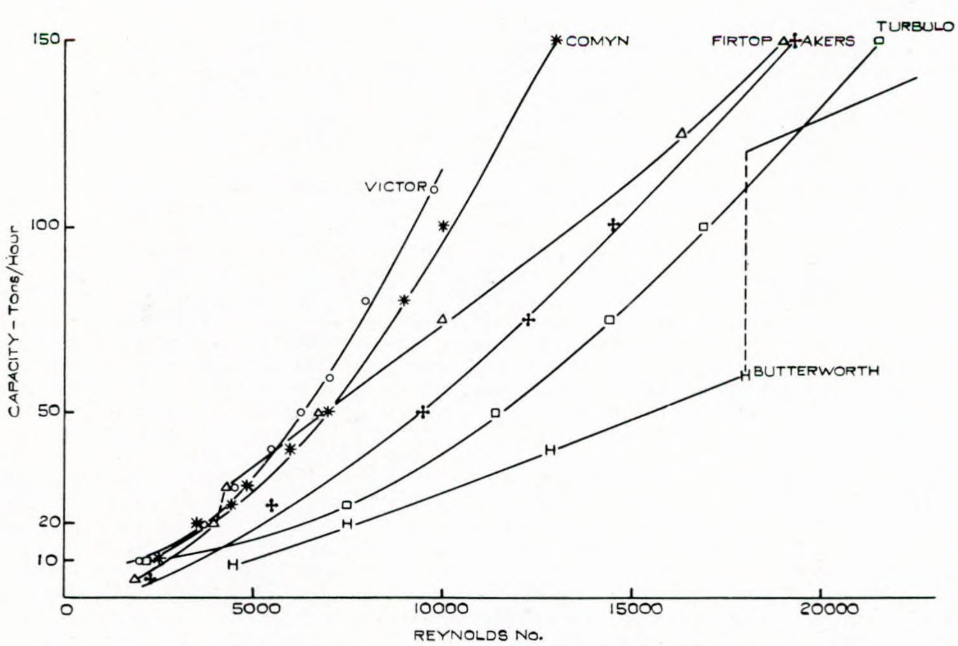

FIG. 20—*Performance comparison of gravity type separators.*

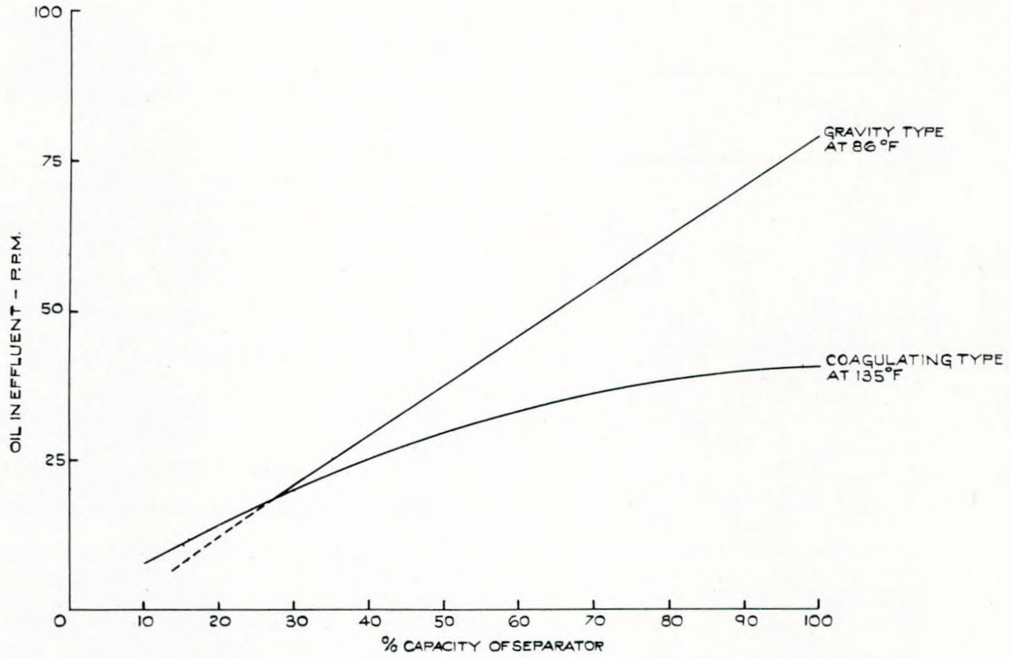

FIG. 21—*Increased perfomance due to reduction of separator capacity.*

While these are very accurate analytical methods, they can only be carried out by professional analysts under laboratory conditions and are, therefore, considered unsuitable for use on board ship.

The remaining methods depend mostly upon the use of a light source at varying levels within the electromagnetic spectrum, i.e. ultra-violet, visible or infra-red light, and again most of the available equipment in this range is produced for use in a laboratory or for various industrial applications, but some manufacturers have produced monitors or are interested in adapting monitors for use on board ship.

Infra-Red and Ultra-Violet Absorption

Atoms or groups of atoms vibrate at definite frequencies and when they are radiated by an energy source whose wavelength corresponds to that vibrational frequency, absorption of the energy takes place.

All elements can be detected by this method, but each element requires a light source from a region of the spectral range which has a wavelength, characteristic of that element.

These methods operate according to Beer's Law which states that the absorptivity of a substance is proportional to the concentration of that substance. When more than one component is present in the sample, the spectrum of the sample will show the spectra of all the components present superimposed one on the other and since many of the other components will have common absorption bands, errors can be encountered.

Opinions on the suitability of these methods vary, but most manufacturers prefer to measure oil content in water at a wavelength of 3380 to 3500 nm, i.e., in the lower infra-red region. Others claim that a monitor operating in the ultra-violet region would be better as water exhibits intense absorption in the mid infra-red region which may have some effect upon the accuracy of a reading taken in the lower infra-red region.

Fluorescence

When oils and certain other substances are irradiated with light of a suitable wavelength, visible light or fluorescence is produced. The fluorescence of that substance is proportional to the amount of oil present: in other words the oil content of an oil-water mixture.

The most suitable wavelength appears to be in the ultra-violet region, but inaccuracies can occur due to other substances which cluoresce, air bubbles within the sample stream or a change in the fluorescent properties of the sample which can occur with age and temperature.

The type of oil in the sample stream would also have an effect upon such a meter, frequent calibration of the system would, therefore, be necessary.

Turbidity

Turbidity is also referred to as scattered light, suspended solids or clouds of the sample being monitored.

A beam of visible light is directed at the sample and any oil (or solids) present will reflect or scatter part of that light beam.

The light which is transmitted through the sample is compared with the intensity of the light source and the difference is proportional to the oil (or solids) content of the sample stream. The accuracy of such a system is affected by the particle size, density, colour, ageing of the light source, and, of course, by other solid particulate matter in the sample such as sand, rust, mud or mill scale.

Conductivity

Oil is a far better electrical insulator than water, consequently a change in conductivity can be detected and related to the total oil content of the mixture being monitored. Such a system is not very sensitive and small quantities of oil, i.e., less than 5000 ppm cannot be detected by this method.

Available Equipment

The Bailey Oil Content Meter

The Bailey Oil Content Meter shown in Fig. 22 is, so far, the only instrument of UK orgin to be installed on board ship for monitoring any overboard discharge containing oil.

The instrument operates on the principle of ultra-violet fluorescence and to comply with hazardous area requirements, all electrical items are mounted on a panel in the non-hazardous area. Other mechanical and pneumatic items are mounted on the other side of the panel in the hazardous area and connexions are made between the two areas with approved gas-tight seals. A sample is taken from the overboard discharge line and passed via the sample lift pump to the monitor. The sample is first processed by a conditioning unit which reduces the oil particles to a consistent size. The mixture then flows through a sampling chamber where it is irradiated by the ultra-violet beam and the visible light produced is detected by a sensitive photocell. The signal is fed to a high-gain amplifier and is then used for indicating, recording, and for visible or audible alarms.

A reference standard, comprising a glass disc having a stable fluorescent characteristic, is supplied for calibration purposes. Operation and maintenance can easily be carried

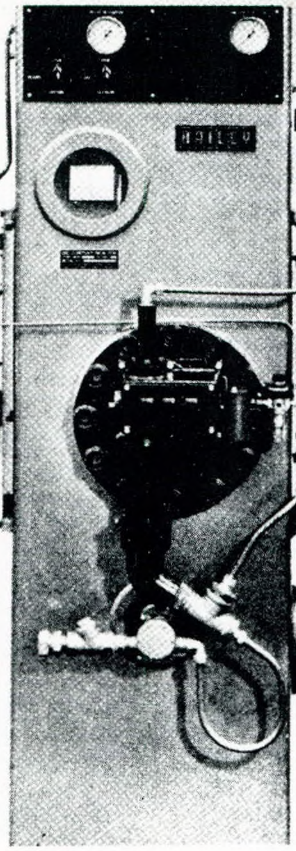

FIG. 22—*The Bailey tanker de-ballasting oil content monitor.*

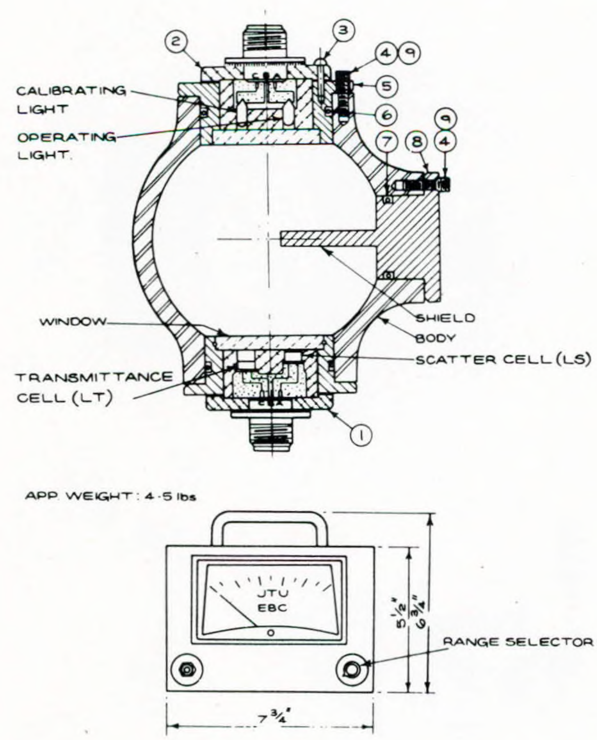

FIG. 23—*The APV-Bowser model 861B turbidimeter.*

out by members of the ship's crew.

It is claimed that the instrument will detect less than 0·5 ppm oil in water and is available in four standard versions, depending upon its remote situation, indicating, alarm and recording equipment.

The APV Bowser Turbidimeter

The APV Bowser Turbidimeter shown in Fig. 23. A sample is fed to a remote sensing head where a beam of light is passed through the liquid. This beam is directed towards two photocells, one of which is in the direct path of the light source, the other being shielded by an insert between the light source and the photocell. In a clear liquid, maximum light is transmitted and none is scattered and only when there are suspended particles in the fluid will any light be reflected on to the photocell which is shielded from the light source.

Two photocells transmit signals which compare the light transmitted to the light reflected or scattered which can be calibrated to parts per million oil in water. The indicator can be mounted in any convenient or safe position and is housed in a metal enclosure containing the meter, calibration control, electronic circuitry and sensitivity range selector.

It is claimed that the instrument will measure within the range 0 to 500 ppm and the indicator is provided with connexions for a chart recorder or alarm circuits, if required. The sensing head is available in two sizes with flow capacities up to 2728 litres a minute (160 tonnes an hour). For larger flows, a by-pass system must be arranged.

The Southern Suspended Solids Meter

This meter is shown in Fig. 24. It was developed by the Water Pollution Research Laboratory and has many shore applications.

A sample is fed to the optical unit where a single light source provides two beams which pass alternatively through a clean sector of a rotating disc at each half revolution. One beam is being continuously monitored by a detector at which the beam is directed. The other beam is directed along a path perpendicular to the detector and the only light which is detected is that which is scattered or reflected by the oil or solid particles within the sample.

The amount of scattered light will be proportional to the amount of oil present provided the reflective power of the suspension remains reasonably constant. Changes in particle size below one micron have little effect, but changes in colour or refractive index are important.

The two signals are fed to the indicating unit which can be mounted in any convenient position and will operate within the range 0 to 1000 ppm oil (or solids) in water. Connexions are available for a recorder and alarm contacts can be added. The equipment operates on a by-pass system and at a sampling rate of 0·2 to 5 litres a minute.

Biospherics Suspended Solids Meter

This meter is shown in Fig. 25.

The principle of operation is based upon light transmitted through liquid and light scattered by the suspended solids or oil particles. The exact details of the monitoring operation are not known but the principle involved has already been described.

The detection unit can be placed in an open channel or saddle mounted on the discharge pipe. A plunger within the detector unit draws in a sample which is held in the path of the light beam, monitored and then discharged. This cycle is repeated each 15 seconds and the constant movement of the plunger, which is also the sample container, prevents any fouling of the sampling unit. The design of the indicator is such that the cyclic nature of the monitoring signals is smoothed out and the instrument only indicates changes in the turbidity of the sample under consideration. The instrument can operate over a range of 0 to 100 ppm and at the most sensitive setting will respond to changes of turbidity equivalent to 1 ppm.

GPM Oil in Water Detector

The GPM Oil in Water Detector is currently used in the U.S.A. in the detection of oil in overboard discharges and in diesel engine cooling-water-systems.

Conductivity probes are inserted into the discharge pipes and the change in conductivity of the mixture is calibrated to the oil content of that mixture. The system is not very

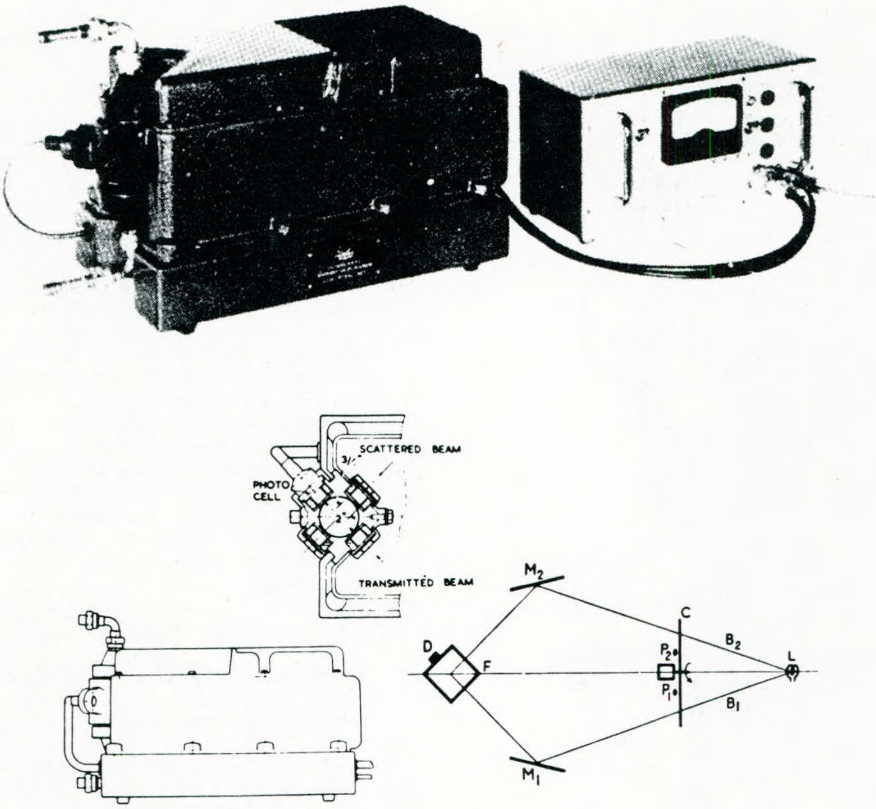

FIG. 24—*Southern analytical suspended solids meter.*

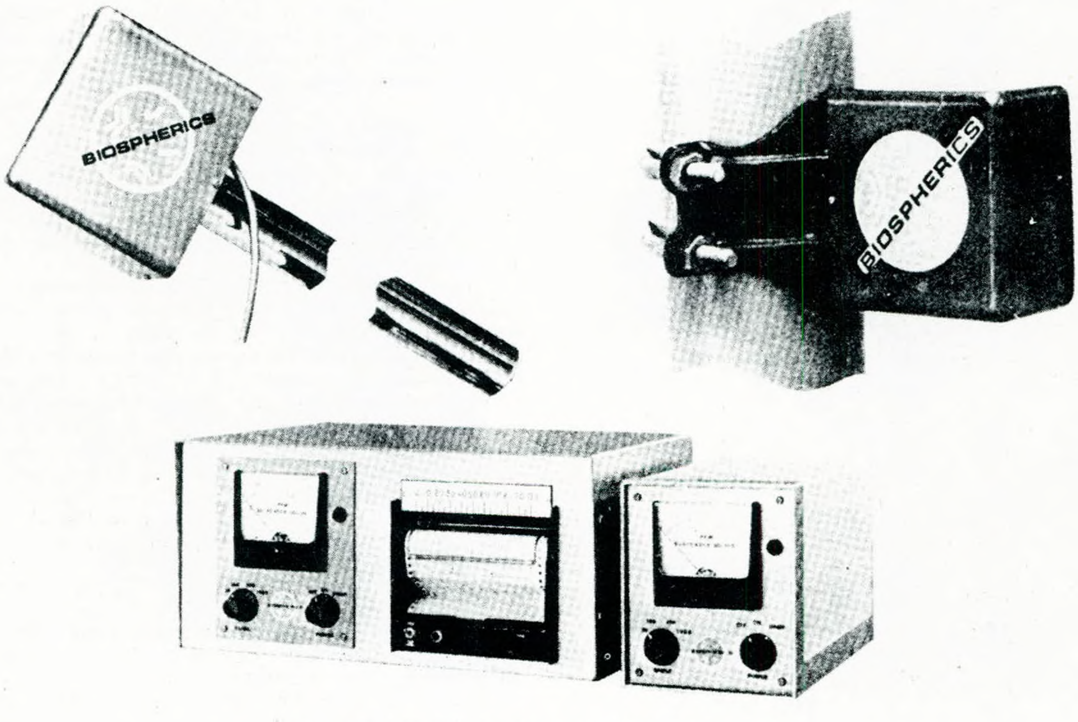

FIG. 25—*The Biospherics suspended solids meter.*

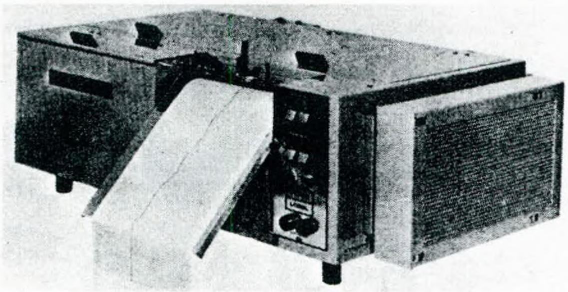

FIG. 26—*The Joyce Loebl flowscan meter.*

sensitive and will not detect oil in water in quantities less than 5000 ppm.

It is claimed that this system is being specified for new ship building and for conversions in the U.S.A. but is more likely that the system is used purely as an interface detector which can operate valves, alarms, etc, when pumping out bilges or fuel tanks containing sea water ballast.

Flowscan Continuous Flow Monitoring Photometer

The photometer shown in Fig. 26 is used extensively in laboratories and in shore-based industrial applications.

The instrument operates on the principle of absorbence and can monitor any element which has a wavelength characteristic within a range of 360 to 900 nm, i.e. covering the range of near ultra-violet, visible and near infra-red spectrum levels.

The system employs a light source which is split alternatively into signal and reference beams by a semi-circular rotating mirror. The reference beam is reflected from the surface of the mirror, through an optical wedge, on to a photomultiplier. The signal beam passes through a sampling unit into another photomultiplier and is compared with the reference beam.

Any difference between the beam intensities drives a servo-motor which turns the optical wedge, altering the path length through the wedge which has known light transmittance properties until the signal and reference beams are balanced.

The servo-motor also drives a pen recorder which produces a linear record of the reference beam and, therefore, of the sample absorbence.

High accuracy is claimed and alarms can be added to indicate an excess of contaminant or to operate shut down procedures.

Oil Pollution Monitor Type 4967

Oil Pollution Monitor Type 4967 is currently used for measuring trace concentrations of hydrocarbons in boiler condensate, etc. The instrument operates on the principle of ultra-violet fluorescence which the manufacturers claim is only suitable for monitoring oil in pure water such as the application stated.

The sample is fed to a quartz cell which is irradiated by filtered ultra-violet light. The fluorescence produced by the presence of oil, etc, is detected by a photomultiplier tube which transmits the necessary signal for indication and alarms. This particular instrument also monitors the temperature of the sample which, in this particular application, is not very important.

The instrument is designed for the detection of oil in boiler condensates in quantities below 10 ppm, but can easily be modified to suit applications requiring a wider range of indication.

The Fram Fluid Analyser

This analyser has been developed along with the Fram/Akers oily water separation system which has already been described. The instrument, as shown in Fig. 27, operates on the principle of infra-red absorption and is suitable for operation within the range 0 to 100 ppm. The monitor consists of a sampling pump, emulsifier, optical unit, direct read-out meter and chart recorder, along with all other necessary controls, i.e., visible alarms, scale multiplier, monitor adjustment and zero calibration.

The equipment can be supplied complete in an oil-tight console unit or the items can be supplied separately for mounting in existing consoles. The monitor operates on full stream up to 25 gallons a minute and on a by-pass system for quantities in excess of this figure.

It is claimed that the equipment monitors only the oil content of the sample stream, independent of solids level as the infra-red source is at such a wavelength, i.e., approximately 7000 Ångstroms as to discriminate between oil and solids. The manufacturers claim, however, that at a wavelength of 7000 Ångstroms, the absorption differential between the oil and background water containing siliceous material is greater than at the normally accepted level of 3380 to 3800 nm (33 800 to 35 000 Å) thus improving the accuracy of the method for this particular application.

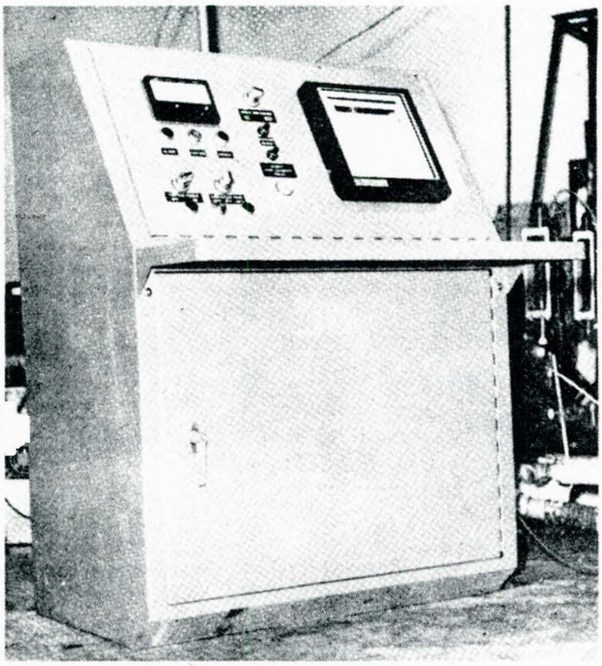

FIG. 27—*The Fram fluid analyser.*

FIG. 28—*Fram trace oil analysis kit.*

The instrument is quickly calibrated to zero ppm for clean water without the use of a test block or other accessories after which fine adjustment can be made to the calibration of the instrument by using the Fram trace oil analysis kit, shown in Fig. 28. This equipment is fully described in Ref. [10] and six samples can be accurately analysed in less than 45 minutes. The kit is easy to operate and accurate results can be obtained by anyone with a small amount of training. The kit is very compact and is supplied in a foam-lined carrying case, making it very portable.

Discussion

The methods described are not the most accurate, but are probably the most practical for the detection of oil in water, away from laboratory facilities. All the methods are affected by impurities or solid matter suspended in the water. In particular, the absorption and fluorescence methods are affected by the presence of water apart from whatever impurities they carry.

In the laboratory, water is avoided as a solvent because of its own spectrum in the infra-red region and a very noticeable violet fluorescence when irradiated with ultra-violet light. This is mostly caused by impurities and gradually reduces if distilled repeatedly but is never totally eliminated.

Table I gives details of tests carried out by a manufacturer of fluorescent oil-content monitors where the pollution levels are indicated using equal amounts of oil in sea water and distilled water. The difference between monitoring pure water and sea water presents one of the greatest difficulties as clean sea water contains approximately 32 000 ppm dissolved solids, the greater proportion of which, (30 000 ppm) being sodium chloride or salt. In total, some 77 chemical elements have been detected or inferred to be present in sea water although the greater majority are present in quantities of less than 0·5 ppm.

Table II indicates the chemical elements and their concentrations in ppm in sea water. Only those whose concentrations are greater than 0·5 ppm are included.

Water from crude tanks will contain some other impurities such as detergents and a large amount of solids which accumulate within the heavy waxes left in the tanks after discharging a cargo. It is reported in Ref. [11] that in the recovery of fuel while de-ballasting fuel tanks, 27 to 36 kg (60 to 80 lb) of earthy solids were produced for each tonne of sludge processed. Sludge which is removed from the lubricating and fuel-oil purifiers is usually dumped into the bilges of a ship and would contain comparatively large proportions of sand, rust, bronze, mill scale, paint, aluminium and other fibrous matter.

In the open sea, particulate content is often as high as 5 ppm and, in some areas, close to shore, 7000 ppm solids content can be found in stable suspension. Introducing 36 kg (80 lb) of earthy solids per tonne of oil discharged during tank washing results in a solids content of 1·35 ppm in the discharge line, when assuming the quantities of oil and ballast water already quoted.

Bearing in mind that tank washing is usually concerned with crude oil where the solids content could be higher than that of refined fuel oil, the solids content of the wash water could increase to, say, 3 ppm. Combining the solids content of the sea water taken from the open ocean and the probable solids content of the remaining crude oil results in a solid particulate content of the oily water mixture of some 8 ppm.

TABLE I — FLUORESCENCE MEASUREMENTS ON VARIOUS MIXTURES OF SEA WATER, CRUDE OIL, RUST AND DISTILLED WATER

Sample Description	QSE*	ppm
Sea water with sand and other solids settled out	15 to 25	3·5 to 6
Sea water, separated from a mixture of sea water, oil and rust by allowing to settle for one day	56	13·3
Sea water and rust after two hour settling	200	47·6
100 ppm oil in distilled water	420	100
100 ppm oil in sea water	630	150

NOTE:
* QSE — Is the quinine sulphate equivalent which is used for the calibration of the meter and at low levels of pollution, and may be related to oil concentration.

TABLE II—CONCENTRATION OF DISSOLVED SUBSTANCES IN SEA WATER

Element		Abundance, ppm
Chlorine	Cl	19 353
Sodium	Na	10 760
Magnesium	Mg	1294
Sulphur	S	812
Calcium	Ca	413
Potassium	K	387
Bromine	Br	67·3
Carbon	C	28
Strontium	Sr	8·0
Boron	B	4·6
Silicon	Si	3
Fluorine	F	1·3
Argon	A	0·6
Nitrogen	N	0·5
Phosphorus	P	7×10^{-2}

It can be seen, therefore, that the overboard discharge after tank washing, de-ballasting fuel tanks, or pumping out bilge water, can contain a considerable amount of foreign matter which would hinder any instrument in the detection of oil in water in quantities ranging from 0 to 100 ppm.

The presence of oxygen quenches or reduces the fluorescence of many aromatic hydrocarbons, consequently any such monitoring systems should be air tight and the sampling stream should be free from air locks or air bubbles. It is not possible to be selective in the choice of wavelength within the ultra-violet range as the fluorescence yield is independent of the irradiating light for practically all fluorescent compounds, including aromatic hydrocarbons. It is also anticipated that the linear increase in the intensity of the fluorescence, with respect to oil concentration will not continue at concentrations over 100 ppm due to the oil not being in true suspension and the quenching of the fluorescence due to the higher oil concentration.

The infra-red absorption method has an advantage over the ultra-violet methods as the wavelength, characteristic of the main constituent to be monitored, lies in the infra-red region. By this means, other elements in the sample stream can, to some extent, be ignored or overlooked as the infra-red light is mostly absorbed by the oil or hydrocarbon content of the sample stream.

Table III is taken from information in Ref. [12] and indicates the variation in the absorptivity of oils. Altogether 22 samples of oil were taken from five refineries of different companies and laboratory samples were prepared, each consisting of 10 ppm oil in carbon tetrachloride.

The absorptivity of each sample was measured by the infra-red absorption method at a wavelength of 3400 nm and the variation from the mean value was found to be −20 to +15 per cent. Add to this the possible absorption by the solids content of the discharge stream, as well as that of water itself, then this method would appear to have an inherent error of not more than ±20 per cent.

Turbidimetric devices would be very much affected by the possible solids content of the sampling stream as previously described. Ref. [13] indicates, however, that the solid particulate matter added to the sample of a fluorescent monitor becomes covered with oil as a higher oil content was indicated when rust was added to the water, and rust itself is not fluorescent.

This would indicate that any solids, i.e. rust, sand, mill scale, etc, would also become coated with oil, particularly as they would originate from the purifiers or crude oil itself. In this way, the suspended solids would be monitored as oil droplets and the indicated oil content would be more than the actual amount.

It is not acceptable to filter the solids from the sample stream only as the main discharge would contain oil-coated particles and the oil-content monitor would indicate a lesser quantity of oil than is actually in the main discharge.

TABLE III—VARIATION IN ABSORPTIVITY OF OILS FROM DIFFERENT SOURCES

Source		Absorptivity (10 ppm in 14 cc)	Deviation from mean, percentage
Lab. 4 — sample	1	0·071	−15
	2	0·073	− 8
	3	0·086	+ 9
	4	0·080	+ 1
	5	0·063	20
Lab. 5 — sample	1	0·069	−13
	2	0·078	− 1
Lab. 6 — sample	1	0·072	− 9
	2	0·070	−11
Lab. 1 — sample	1	0·077	− 2
	2	0·088	+11
	3	0·074	− 6
	4	0·080	+ 1
Lab. 7 — sample	1	0·076	− 3
	2	0·075	− 4
	3	0·094	+15
	4	0·074	− 5
	5	0·091	+12
	6	0·092	+13
	7	0·071	− 8
	8	0·082	+ 3
	9	0·093	+14

The Fram/Akers separation system includes pre-conditioners which remove a large proportion of the oil and solids content of the water before treatment in the emulsion breaker and the separator. The discharge from the separator will, therefore, be relatively free of solids and greater accuracy would be obtained when monitoring this discharge with any of the instruments described.

Due to the motion of a ship as sea, i.e., rolling, pitching and vibration, instruments with moving parts, such as rotating discs cutting the light source, are not desirable. Instruments falling into this category are manufactured by:

i) Southern Analytical Limited;
ii) Biospherics Inc.;
iii) Joyce Loebl and Company Limited.

Although the unit manufactured by Biospherics Inc., has certain other advantages in the self-cleaning action of the sampling system. The remaining instruments are manufactured by:

a) Bailey Meters and Controls Limited;
b) APV Bowser Filtration Limited;
c) International Combustion Limited;
d) Fram Filters Limited;
e) Galbraith-Pilot Marine Corporation.

Of these, the conductivity method employed by the Galbraith-Pilot Marine Corporation is not suitable for monitoring discharges containing less than 5000 ppm oil in water and is best suited for the detection of an oil-water interface in a separator or slop tank.

The instrument developed by International Combustion Limited is considered by the manufacturers not to be sufficiently accurate in monitoring the oil content of contaminated water and is recommended for use as an interface detector only. The sampling system of the instrument also contains moving parts in the form of a rotating drum which, in this case, is not a major drawback. The remaining three instruments operate on principles of:

1) fluorescence;
2) turbidity;
3) infra-red absorption.

Of these, the Bailey Fluorescent Oil Content Meter is in use on board ship and high accuracy is claimed. The calibration of this instrument is carried out by using a glass disc as a reference standard and not by using the sea water which may eliminate some of the inaccuracies. Due to the changing nature of the sea water with geographical location and temperature, however, high accuracy is not considered possible, even with frequent calibration.

The APV Bowser Turbidimeter is not affected by the dissolved solids content of the sea water and it is expected that any solid particles will be oil-coated; the instrument will, therefore, always show a higher oil content than the actual oil content in the overboard discharge. High accuracy is not anticipated but the oil content could not be greater than that indicated.

The Fram Infra-Red Absorption Meter is intended for use with the Fram/Aker oil-water separator system where a large proportion of the solids content of the discharge stream is removed prior to being monitored. The wavelength of the infra-red light source is at such a level as to avoid, for the most part, the monitoring of the dissolved solids and other impurities of the sea water.

It is expected, therefore, that this instrument will produce the most accurate indication of oil in an overboard discharge provided that the solid particles are removed from the discharge stream and that the instrument is calibrated using the Fram oil analysis kit so that the variation in absorption of the oil can be eliminated.

COSTS

Tables IV, V, VI and VII show the approximate relationship of the first costs of oily water separators from four companies and oil content meters).

PRACTICAL LIMITS OF OIL DISCHARGE

Modern marine separators in use at sea, when in good condition and properly maintained produce effluents of less than 100 ppm. Doubling the size of these units would probably lead to effluents of less than 50 ppm oil content. Fitting filters on the outlet side of the standard sized unit can probably result in lower oil contents. If the claims made by Fram for their units are substantiated effluents of 10 ppm are practical.

TABLE IV — RELATIVE FIRST COSTS OF MANUALLY OPERATED OILY WATER SEPARATORS

Capacity tonnes/h	Comyn	Victor	Fram/Aker	Butterworth
2	0·1	0·07		0·15
4·6			0·4	
5	0·14	0·1		
8				0·29
9			0·55	
10	0·16	0·24		
20	0·17	0·26		0·4
22·6			0·64	
25	0·17			
30	0·2	0·29		
40	0·23	0·33		0·55
45			0·72	
50	0·24	0·38		
60		0·39		0·63
68			0·86	
80	0·29	0·42		1·14
90			1·06	
100	0·37	0·44		
120				1·31
125		2·27		
135			1·55	
150	0·45			
175		2·37		
180			2·65	
200	0·59			1·77
225		2·49		
250	0·7			2·01
275		2·63		
400				3·53
500				4·04

TABLE V — RELATIVE FIRST COSTS OF SEMI-AUTOMATIC OILY WATER SEPARATORS

Capacity tonnes/h	Comyn	Victor	Fram/Aker	Butterworth
2	0·15			0·13
4·6			1·06	
5	0·18			
8				0·30
9			1·41	
10	0·21			
20	0·22			0·40
22·6			1·9	
25	0 22			
30	0·24			
40	0·28			0·55
45			2·23	
50	0·28			
60				0·63
68			2·75	
80	0·31			1·15
90			4·02	
100	0·41			
120				1·31
135			5·78	
150	0·43			
180			8·25	
200	0·63			1·77
250	0·76			2·02
400				3·53
500				4·04

TABLE VI — RELATIVE FIRST COSTS OF FULLY AUTOMATIC OILY WATER SEPARATORS

Capacity tonnes/h	Comyn	Victor	Fram/Aker	Butterworth
2	0·16			0·13
4·6			2·47	
5	0·19	0·22		
8				0·29
9			3·1	
10	0·22	0·32		
20	0·23	0·35		0·4
22·6			3·77	
25	0·25			
30	0·27	0·34		
40	0·29	0·42		0·55
45			4·79	
50	0·31	0·44		
60		0·47		0·63
68			6·83	
80	0·37	0·5		1·14
90			8·03	
100	0·44	0·52		
120				1·31
125		2·42		
135			11·07	
150	0·52			
175		2·53		
180			17·91	
200	0·68			1·76
225		2·61		
250	0·81			2·02
275		2·78		
400				3·53
500				4·03

TABLE VII — RELATIVE FIRST COSTS OF OIL-CONTENT MONITORS

Manufacturer	Method	Cost ratio
APV Bowser	Turbidity	0·19
Bailey	UV Fluorescence	1·10
Biospherics	Turbidity	0·33
Fram	IR Absorption	1·06
Galbraith	Conductivity	
I/Nal Combustion	UV Fluorescence	
Joyce Loebl	IR and UV Absorption	0·50
Southern Instruments	Turbidity	0·17
Fram	Trace Oil Analysis Kit	0·09

Taking into account the type of service that can be expected at sea, a practical attainable figure for effluents from units up to 500 tonnes an hour capacity is about 20 ppm.

DISCUSSION

Separator efficiency can be improved by merely increasing the size of the unit and the figures in the report indicate that worthwhile gains in preventing pollution from oily bilges could be made at relatively little cost merely by fitting larger separators or fitting second stage filters.

Separation by electrolysis, which was proposed by Pollution Technical Services Limited, produces effluents which are only comparable to effluents from currently used gravity separators and the first cost is several times greater.

Of the various types of separators readily available in this country for marine use the quality of the effluent is similar in each case. The coalescing type is heavy as it contains a large pebble bed. One of the gravity types is not pressurized and, hence, cannot be mounted below the water line, but its design is such that its action is automatic and neat oil cannot pass into the discharge line. This unit, is, however, multistage and the interstage connexions are highly turbulent.

New methods have also been investigated and these include:

i) Centrifugal separation;
ii) Dialysis separation;
iii) Reverse osmosis separation.

Centrifugal separators are only available for relatively small through-puts and the performance level is only comparable to that of gravity-type separators. The other two methods are generally only available as laboratory equipment and both appear to be limited to extremely small particle size of the distributed fluid and the quantities of oil envisaged would soon foul those separators.

Means of removing oil from drinking water has also been examined as this may be relevant particularly with regard to the large quantities involved. Harris [14] of the Lee Valley Water Company has reported:

> "The only known method of removing oil from water which might be applied to public water works is by the use of a diatomaceous earth filter. Such a filter might or might not be effective but the best performance which can be expected is the removal of oil up to 5 ppm . . . the overall cost of such a plant . . . needed to treat 6 000 000 gallons of water a day, amounted to £120 000 and operating costs, i.e., the cost of powder to be used in the plant would be £105 a day."

The systems approach adopted by Fram Filters Limited, along with the tilted plate separator manufactured by C.J.B. claim the highest effluent quality of less than 10 ppm.

CONCLUSIONS

This paper has assessed methods available to prevent pollution of the sea by oil contained in the overboard discharges of ships. With certain reservations, figures supplied by oil companies and separator manufacturers have been used as a basis of the paper and the following overall conclusions drawn.

Separators

The development of the gravity/coalescer type of separator appears to have reached its limit and can produce an effluent containing approximately 50 to 80 ppm oil in water under operating conditions at sea. The quality of the effluent can be improved by increasing the size of the separator unit thus reducing the velocity of flow and increasing the degree of separation.

Further improvement can be effected by the addition of a filter unit to the gravity/coalescer separator and the oil content of the effluent can probably be reduced to less than 20 ppm under operating conditions at sea. Claims of less than 10 ppm are made by Fram Filters Limited and C.J.B. Developments.

Monitors

None of the instruments investigated can give an absolutely accurate indication of the oil content of an overboard discharge stream owing to the nature and impurity level of that discharge stream. Of the instruments investigated, the most accurate was the Fram Fluid Analyser but the accuracy depended upon calibration by the trace oil analysis kit and the removal of oil-coated particles from the discharge stream. Under normal circumstances, these solids are not removed in which case it would be more acceptable to count them as oil droplets and monitor the discharge with the APV Bowser Turbidimeter. The accuracy of this meter depends upon the solids content of the discharge stream which is not expected to represent more than 10 ppm oil in water.

Operational

The use of improved, reliable monitors, in conjunction with the load-on-top techniques, is likely to be more cost effective than improved de-ballasting separators.

APOLOGY

In view of the delay in general publication which has occurred since the study was undertaken the authors wish to apologize to any manufacturers involved who feel that their products are presently showing considerable improvement in performance over that stated in the text. It is to be hoped that they and others will take the opportunity to redress any such situation which may have occurred by forwarding details of advances made for inclusion in discussion.

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