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REPORTS ON NINE STUDIES

Attached hereto is a copy of the final report of Study No. VIII - Ship-generated sewage treatment and holding systems - submitted by the Government of Canada.

Due to the limited number of copies available only one copy per delegation of the report (in English or French) will be distributed during the Conference.

Transport Canada Transports Canada

VESSELS SEWAGE TREATMENT SYSTEMS

STUDY VIII
I.M.C.O. MARINE POLLUTION SUB-COMMITTEE

I.M.C.O. SUB-COMMITTEE ON MARINE POLLUTION

REPORT ON SHIP GENERATED SEWAGE TREATMENT AND RETENTION SYSTEMS

Preparation for an International Conference on Marine Pollution in 1973

INTRODUCTION

This report has been prepared by Canada as lead country on the basis of information available in Canada and on that provided by Japan, Sweden, the United Kingdom and the United States of America, including the following:-

1. National Academy of Sciences, Washington, U.S.A., MRIS report on the treatment and disposal of vessel sanitary wastes.

2. On board sewage treatment systems by W.R. Minden, U.S. Army Corps of Engineers.

3. Outline for study of ship-generated sewage treatment and holding systems, Ministry of Transport, Japan.

4. Gibbs & Cox Inc. report no. M71-8, Investigation of the Control of Sewage from Existing Passenger Vessels.

5. The Control of Sewage from Commercial Ships by R.W. Parsons, Ministry of Transport, Canada.

The report is divided for easy reference into the following sections:-

1. General description of methods for treating or retaining sewage on board ship.

2. Evaluation of the various systems.

3. Estimation of capacities and sizes.

4. Estimation of capital costs.

5. Estimation of operating costs.

6. Installation feasibility for existing ships.

7. Sewage discharge standards.

8. Various regulatory measures.

1. General description of methods for treating or retaining sewage on board ship

(a) Holding Tank

The holding tank represents the simplest form of retention system. As shown in figure 1 the basic system consists of a holding tank of suitable capacity for the number of persons aboard the ship, the daily per capita influent and the number of days between discharges ashore, a pressurized water supply to flush out compacted solids in the tank when cleaning, and a discharge pump and piping to suitable deck fittings for pumping ashore or overboard where the latter is permitted. An air supply may also be provided to prevent the sewage from becoming anaerobic and to keep solids in suspension.

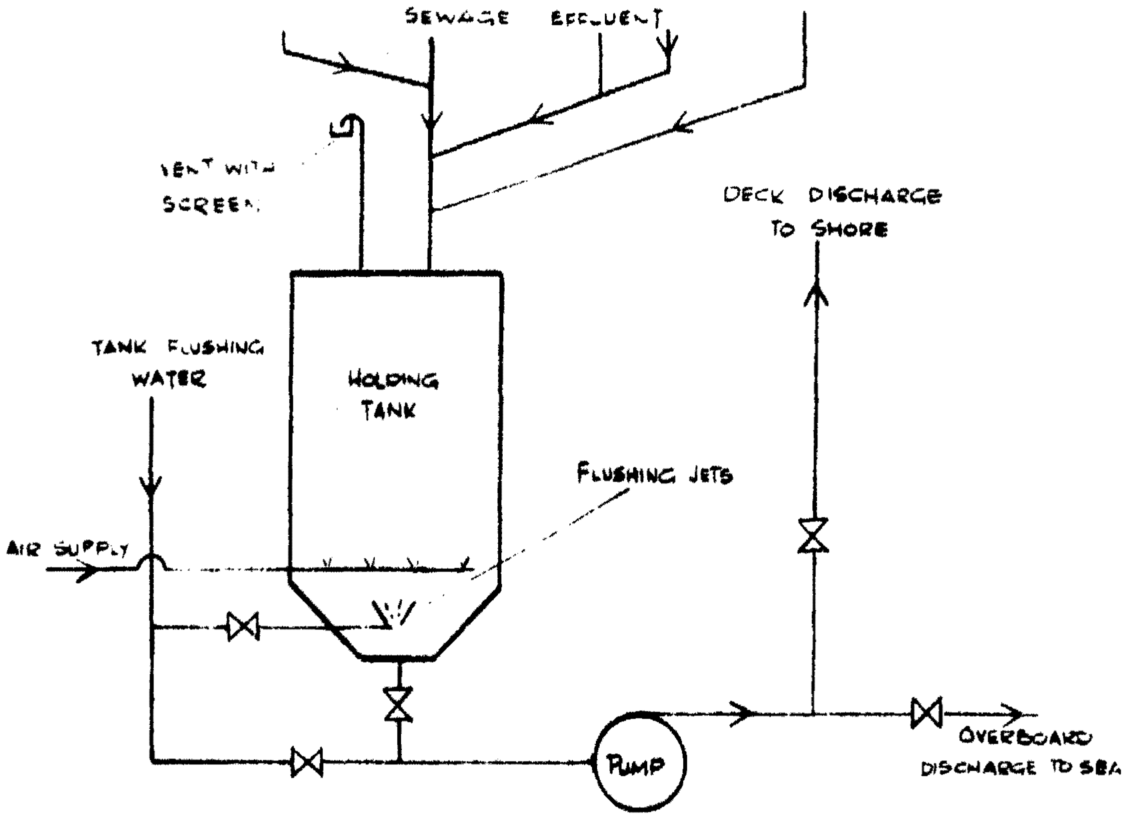

Fig: 1 Holding Tank

In larger ships the holding tank is usually designed with a hopper bottom and with external stiffeners in order to maintain clean smooth interior surfaces. Because of the nature of its contents and also for draining and cleaning requirements it is desirable that the tank be a completely separate unit from the ship structure. The tank is usually located so that the sewage is conveyed to it by gravity. Suitable venting arrangements, opening away from personnel areas must be provided and these must be protected by flame screens due to the combustible nature of the gases which may be emitted when anaerobic decomposition occurs in the tank. Anaerobic conditions may be prevented by the addition of chemicals to sterilize the tank contents or by introducing compressed air into the tank to create aerobic conditions.

(b) Recirculating

A recirculating system of a type suitable for use in commercial vessels is shown in figure 2. This system screens, sterilizes and recirculates the liquid in the sewage as flush water and thereby obviates the need for additional water for flushing purposes. The flushing liquid may be a fluid other than water and at least one other system uses a non-aqueous liquid for this purpose. The sewage must, however, be eventually discharged ashore or overboard, or incinerated, together with the accumulated sludge.

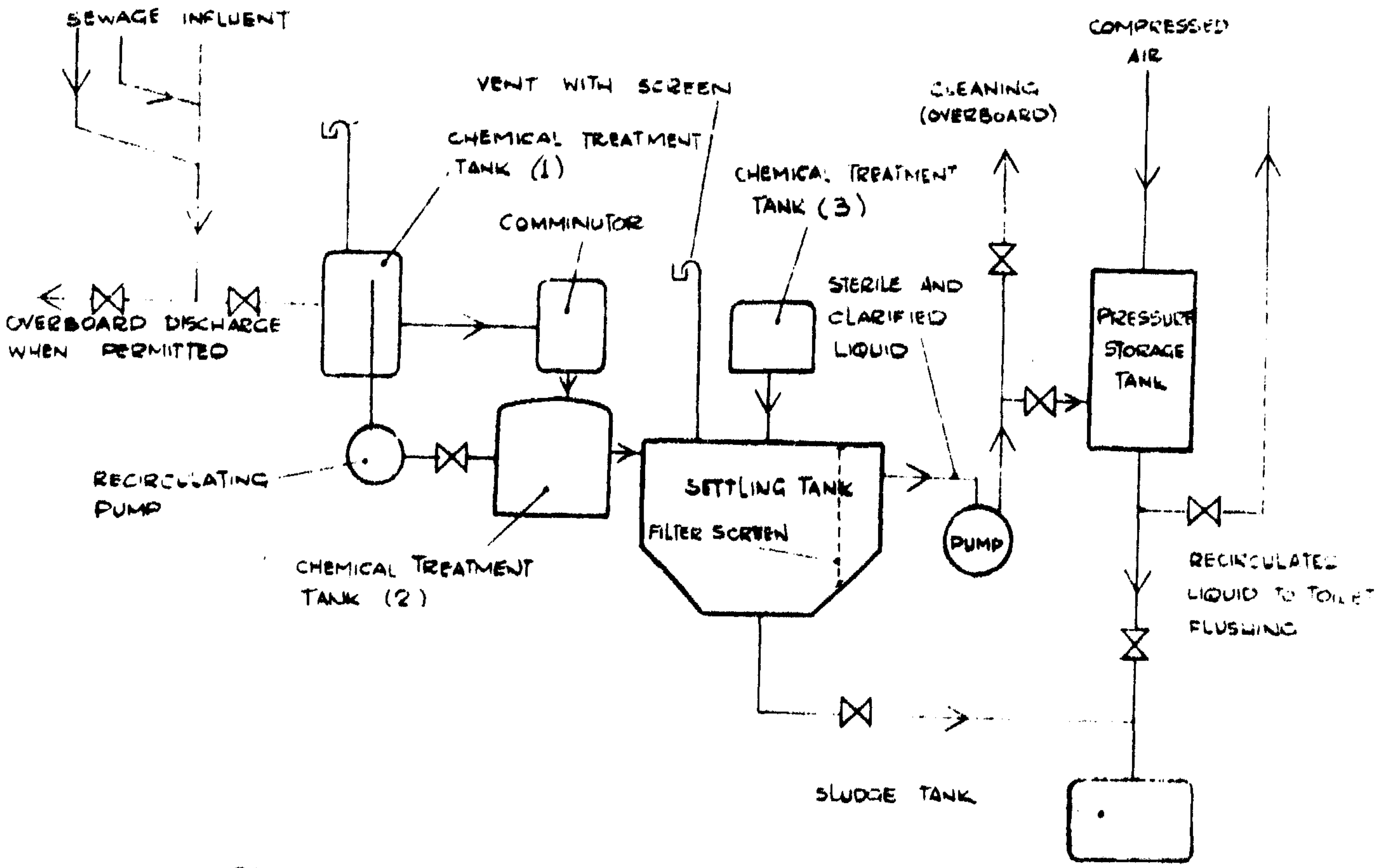

Fig: 2 Recirculating System for Commercial Vessels

The influent, consisting of the waste and recirculated sewage flush water, enters a tank (1) where it is chemically treated for odour and colour control. The sewage then passes through a comminutor or grinder, where the solids are reduced to fine particles, and from there into a second chemical treatment tank (2). A recirculating pump provides continuous circulation to ensure thorough mixing of the chemical and sewage and continuous comminutor action. The resulting liquid is then passed to a settling tank where further chemical treatment takes place to sterilize the liquid and break down the solids until the quantity of suspended matter is minimized. Hypochlorite is commonly used for odour and colour control and sodium hydroxide for sterilizing and solid breakdown purposes. The capacity of the settling tank is designed to hold the liquid for a sufficient time to allow the suspended solid particles to settle out. The sterilized and clarified liquid is then recirculated to the toilet and urinal flushing system. Sludge from the settling tank is drained to the sludge tank for periodic disposal ashore or overboard, or by incineration. The liquid sewage is eventually disposed of by discharge ashore or overboard.

(c) Aerobic

In the aerobic systems the sewage first enters a comminutor and then passes to an aeration tank where, with the addition of air, aerobic bacteria commence a decomposition or oxidation process. After a predetermined retention period in the aeration tank, the liquid is transferred to a settling or sedimentation tank where the heavy solids, in the form of sludge, settle to the bottom while the lighter solids float to the top. The sludge is recirculated back to the aeration tank to feed back sufficient aerobic organisms to maintain the process and for further oxidation. Floating solids in the settling tank are also returned, via a surface skimmer, to the aeration tank. Vents are provided on the settling and aeration tanks to conduct gases and excess air to the atmosphere.

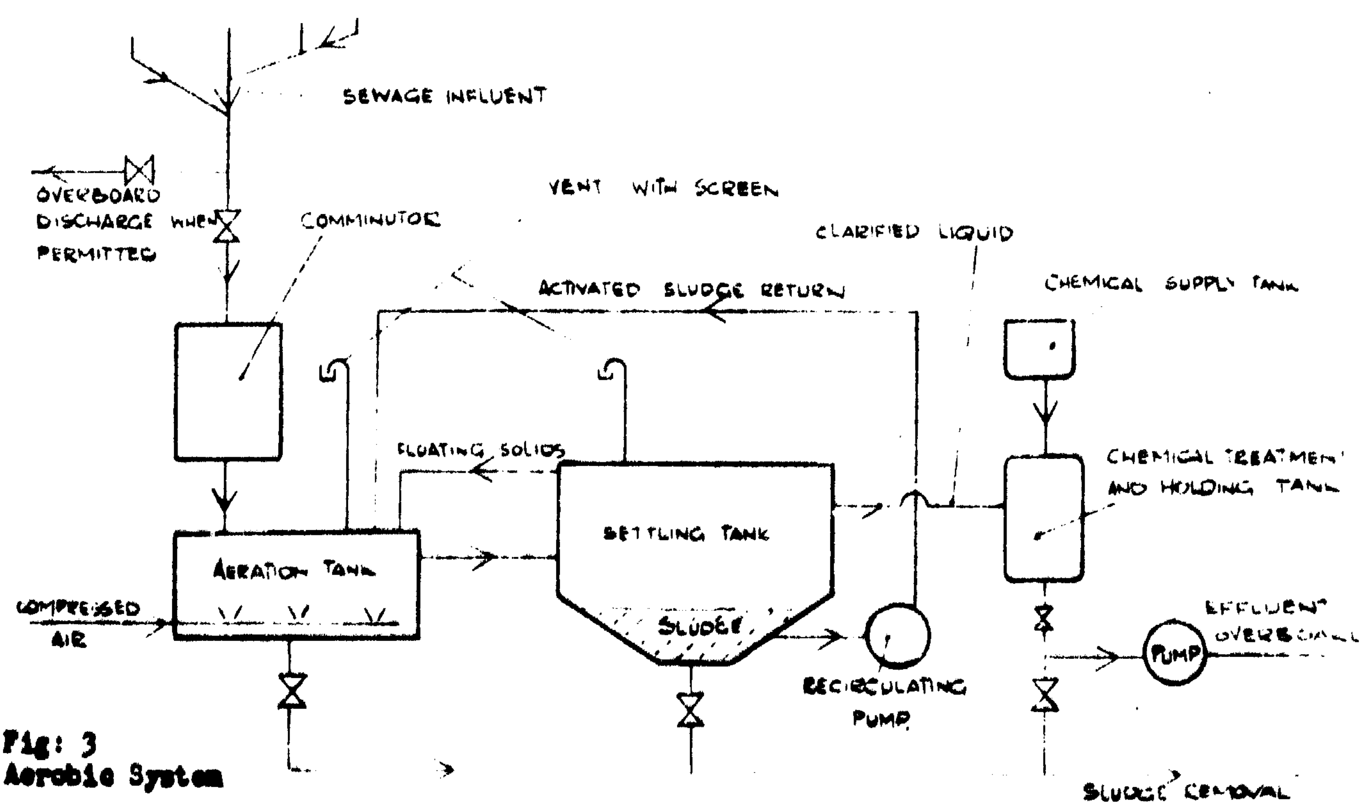

Fig: 3
Aerobic System

The clarified liquid is then passed to the chemical treatment and holding tank where chlorination takes place. After a sufficient holding time the disinfected liquid is discharged overboard. Provision is made in the system to periodically remove sludge from the settling tank. In order that the desired degrees of oxidation and sedimentation are obtained a retention period of from 12 to 24 hours is required in the aeration tank, and from 2 to 4 hours in the settling tank. A retention period of 30 minutes in the chemical treatment tank ensures disinfection of the effluent. In some systems the aerobic oxidation process is accelerated by heating the aeration tank.

(d) Anaerobic

These systems are similar to the aerobic systems except that the biological digestion takes place in the absence of oxygen and aeration is not used. The results have been found to be unsatisfactory for use on board ship because:

(i) tank sizes have to be larger and retention times have to be longer because anaerobic bacteria are slower acting than are the aerobic type.

(ii) the anaerobic process results in the release of noxious, odorous and toxic gases.

(iii) highly corrosive by-products are produced, and

(iv) difficulty has been found in achieving the desired effluent standards.

For these reasons a description of the system has not been undertaken in this report.

(e) Electro-Chemical

The sewage enters a holding tank which absorbs the fluctuations in load and ensures a constant flow rate into a comminutor or grinder. Air is supplied to the holding tank to maintain aerobic conditions during storage. When a predetermined level is reached in the holding tank, the liquid is pumped through the comminutor into an electro-coagulation cell which consists of a tank with parallel steel plates immersed in the liquid which have an electric potential between alternate plates from a direct current supply. In the ensuing electrolytic action, ferrous hydroxide is produced which combines with the negatively charged sewage to form a micro-floc. The electro-coagulation cell also produces ozone which helps to reduce the B.O.D. content by oxidation. When sea water is used for flushing purposes, chlorine is also generated and this gas aids in disinfection.

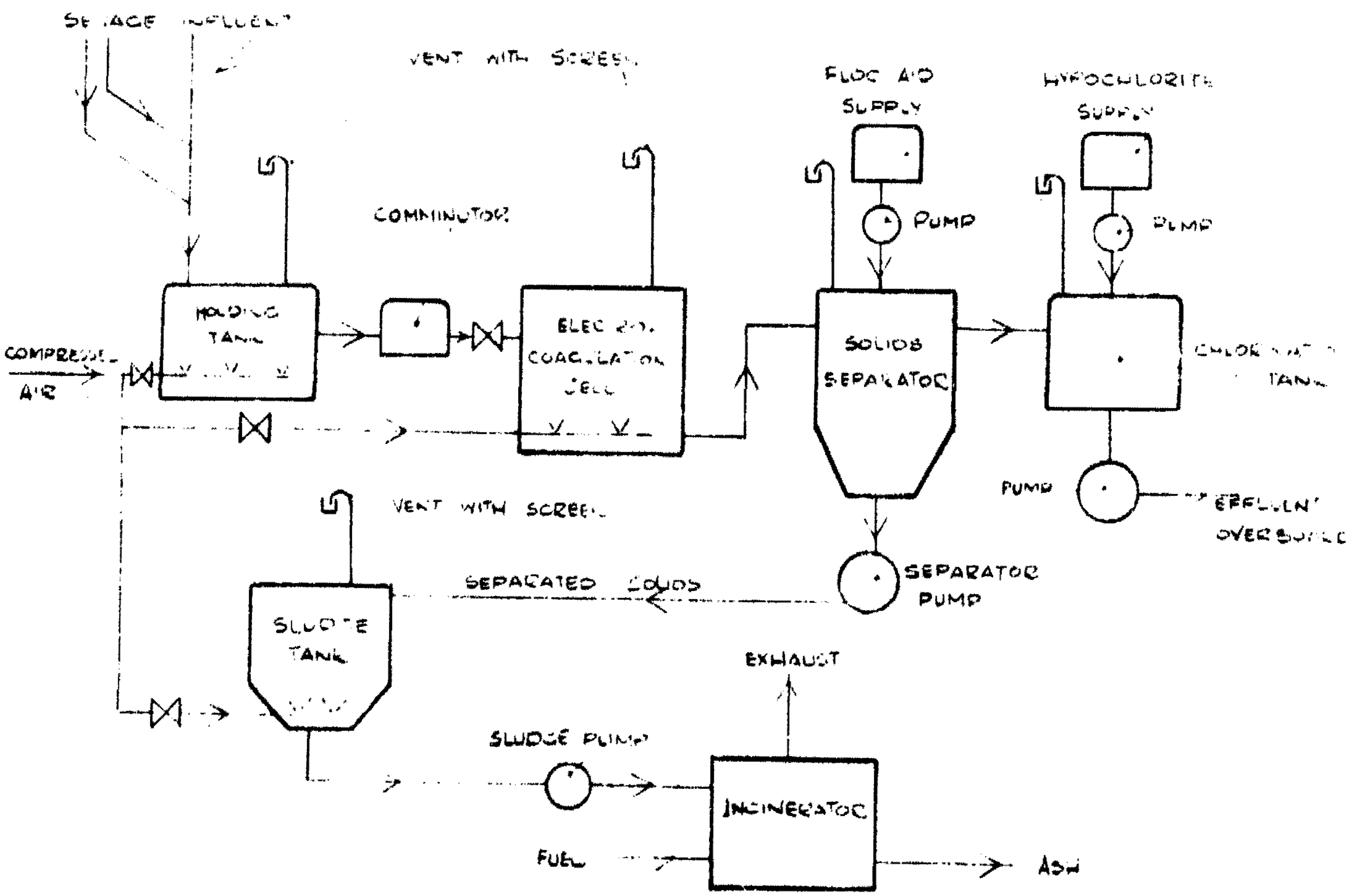

Fig: 4 Electro-Chemical System

After passing through the cell the liquid is pumped to a solids separator where the addition of sodium aluminate coagulates the floc and finely divided particles of suspended solids into larger particles which then settle out and the clarified liquid drawn off. These separated solids are pumped into an aerated sludge tank and then to a chlorination tank for disinfection and discharge overboard. The solid contents of the sludge tank are discharged to an incinerator and the resulting inert ash discharged overboard.

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(f) Separator-Chemical

In this system the sewage first enters a solids separation and holding tank where the heavier solids are separated and passed to a sludge tank. The liquid waste from the separation tank is transferred to a coagulation and disinfection tank where the fine solids are coagulated and separated from the liquid by the addition of aluminum sulphate or ferric chloride, and the liquid disinfected. Separated solids from the coagulation tank are passed back to the sludge tank and the clarified liquid discharged overboard. The sludge is then fed to an incinerator and the resulting inert ash discharged overboard.

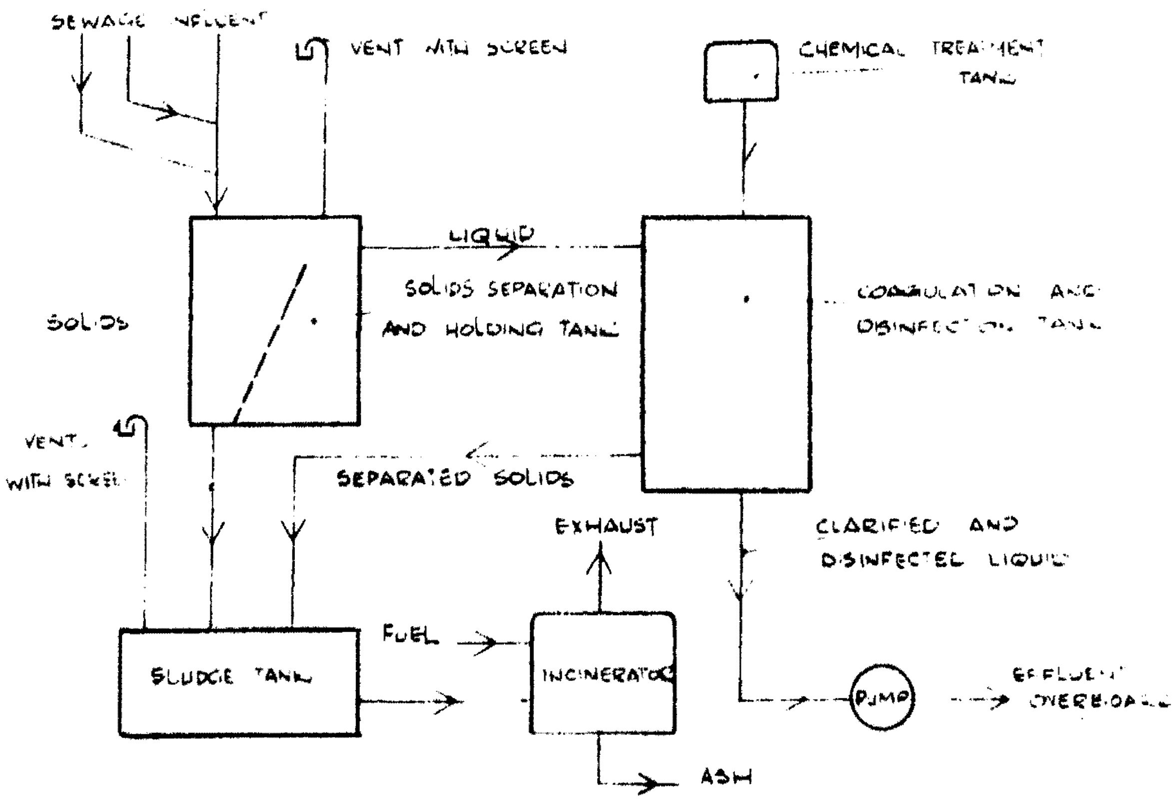

Fig: 5 Separator-Chemical System

(g) Electro-Mechanical

In this system the sewage enters a separation tank in which coarse solids are separated from the liquid. These solids are then passed to a storage and transfer tank from which, at predetermined time intervals, they are transferred to an incinerator.

The liquid, after passing through the separator, goes to a holding tank which retains it until a predetermined level is reached, at which time a feed pump discharges the holding tank contents into a liquid purifier tank unit which is basically the same as the electro-coagulation cell described in the Electro-Chemical Treatment System. In the liquid purifier tank, the oxygen and hydrogen gas generated therein carry the suspended particulate solids (micro-floc) to the surface where a scraper removes them and passes them to the storage and transfer tank for eventual transfer to an incinerator. The clarified liquid from the purifier tank is discharged overboard.

(h) Macerator-Chlorinator

In this system the sewage waste proceeds from the toilets to a macerator pump where it is macerated and then passed to a chlorination tank for disinfection by chlorine prior to overboard discharge. The maceration process breaks down the sewage and permits more efficient chlorination, but has little other effect in improving the quality of the effluent. The macerated sewage is retained in the treatment tank for sufficient time to reduce the coliform bacteria, after which it is discharged overboard. It should be noted that it is rarely possible to achieve a complete sterilization because of the high solids content.

(i) Retention with Vacuum Transport of Sewage

Such systems use air instead of water as the main transportation medium. The system is maintained under a constant vacuum of one half atmosphere. The toilets and urinals are flushed with a minimum of flush water which is removed by means of air being drawn into the system and forcing the sewage and flush water through the piping, in the form of a plug, to the holding tank. The flushing mechanism on the toilets and urinals gives a flushing period of approximately 7 seconds and the quantity of flushing water is reduced by about 75%. Smaller diameter piping can therefore be used and as the transportation of the waste does not rely upon gravity forces, the piping does not require to be sloped downwards and can be led around or over obstacles.

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(j) Heater Evaporative

In this system a holding tank is initially charged with about ten gallons of fresh water, dye, disinfectant solution and an anti-foam agent. When a pre-selected level of waste has been reached in the tank, level sensors actuate a macerator pump which removes and macerates the sewage until the 10 gallon level is again reached. The macerator pump conveys the sewage to a 50 gallon evaporator tank where additional dye and disinfectant are added. When more than 30 gallons of waste slurry and service liquid have been collected in the evaporator tank, a level sensor turns on electric heaters which are mounted on the tank and which heat and evaporate the liquid until a level of less than 30 gallons is reached. This process of intermittent evaporation continues until the remaining 30 gallons in the evaporator tank has achieved a high solids content, after which it is removed for incineration.

(k) Boiler or Stack Evaporation

In these systems the sewage is passed from the toilets to a macerator in which the solids are broken down for intimate mixing with the liquid content, after which the mixture is discharged to a holding tank. The contents of the holding tank are then pumped at a reduced rate through a spray nozzle into either the furnaces of the ship's boilers or the exhaust pipe of a diesel powered ship where it is evaporated and passed to the atmosphere with the exhaust gases.

2. Evaluation of the efficiency, advantages and disadvantages of the various methods of treatment or retention of sewage

(a) Holding Tank

Designed for retention purposes only, this system is not intended for the on-board treatment of sewage. However, where air is supplied to the tank aerobic action may take place which will result in some reduction of suspended solids and B.O.D.'s. Similarly, when chlorine sterilization is used, coliform bacteria will be reduced. Owing to the need to minimize volume of waste being retained in the tank this system is suitable only for body sewage waste storage.

Advantages

(i) Simple construction and free of complicated mechanical equipment, controls and automatic gear.

(ii) Can be used in waters where discharge overboard is prohibited.

Advantages (cont.)

(iii) Can readily be adapted to fit existing space available in ship.

(iv) Requires minimal surveillance.

Disadvantages

(i) It may be necessary to periodically discharge the sewage to a shore reception facility. Problems may result from this as the majority of harbours are not presently equipped with such facilities. Use of barges or tank truck could result in higher costs of disposal and loss of operating time for the vessel.

(ii) Tank size can be excessive if a long retention time is required.

(iii) Anaerobic conditions are likely to occur in the tank resulting in potentially hazardous and polluting conditions in the form of flammable and obnoxious gases.

(iv) For health reasons and in order not to hinder safety inspection of the ship's hull, the tank must be separate from the ship; hence double bottom or other ship's tanks cannot be used.

(v) Space for installation of tank on board may not be readily available in the case of ships having a complement of more than 50 or engaged on long voyages in waters where treatment is required.

(b) Recirculating

These systems are primarily designed to handle only body waste and, as the liquid is recirculated as flush water, treatment is restricted to the separation of solids and the sterilization of the recirculated liquid. This treatment does reduce the coliform bacteria but has little effect on B.O.D. and suspended solids.

Advantages

(i) Can be used in waters where discharge overboard is prohibited.

(ii) Considerable reduction in size compared with holding tank system or, conversely, retention period greatly extended.

(iii) Suitable for use on long voyages in waters where overboard discharge is prohibited.

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Disadvantages

(i) Some difficulty has been experienced in controlling the discolouration level of recirculated fluid, maintaining required alkalinity level and avoiding calcium encrustation of toilets.

(ii) In waters where overboard discharge is prohibited there may be a need for periodic disposal of holding tank contents to a shore reception facility. The problems of discharge ashore are, however, not so serious as for holding tank systems due to the small quantities involved.

(iii) System requires daily attendance to transfer separated solids to a storage tank, to test recirculated water for alkalinity level, to assess usage of chemicals and to re-supply these as required.

(c) Aerobic

Aerobic systems work on the principle of aerobic oxidation of organic wastes by aerobic bacteria and are very commonly used ashore at shore facilities. This may be assisted by extended aeration, the use of recirculated activated sludge or the application of heat in order to accelerate the growth and activity of the aerobic organisms.

These systems are designed to reduce the B.O.D., suspended solids and coliform bacteria in the sewage and can also accept galley and waste water. When galley waste is directed to these systems, however, the garbage must be ground and grease traps fitted to prevent grease and oil from entering the system.

Various manufacturers of these systems claim to be able to meet effluent standards equal to or less than 50 mg/litre B.O.D., 150 mg/litre suspended solids, and 240 coliform bacteria per 100 ml. However, tests carried out in Canada on four commercially available treatment plants indicated that such systems had difficulty or could not meet these standards under shipboard conditions without further modifications. Other tests, made by U.S. Coast Guard, Navy and Corps of Engineers, have confirmed these results.

Advantages

(i) Capable of treating raw sewage and other wastes and improving the quality of the discharge.

(ii) Can handle wash water wastes in addition to body sewage.

(iii) Utilize aerobic organisms instead of the less desirable anaerobic.

(iv) Reduce necessity for frequent shore disposal of retained wastes, and is thereby suitable for ships with large complements or engaged on long voyages in waters where treatment is required.

Disadvantages

(i) Erratic operation under shipboard conditions lead to an inability to meet high water quality standards on a continuous basis.

(ii) System cannot be used in areas where overboard discharge is prohibited.

(iii) The biological process is sensitive to many materials such as cleaning fluids, detergents and other chemicals and to extreme temperature changes, changes from salt to fresh water, hydraulic shock loading and shipboard motion in heavy sea conditions.

(iv) For the aerobic organisms to maintain an efficient level of activity and multiply, surveillance is required in order to maintain a balanced supply of oxygen and organic waste.

(v) Sludge deposits in aeration and separation tanks requires periodic removal (usually by hand) and disposal to a shore facility.

(d) Anaerobic

These systems were amongst the first treatment systems to be tried on board ship and followed very closely the simple septic tank method used by shore treatment facilities. While giving good results ashore they have been found inefficient for shipboard use due to the large sized tanks required, the long retention times needed and the deleterious effect of ship movement. They are also unsuitable for shipboard use because of the odorous and noxious gases that are produced.

Advantages

(i) Considerable shore experience available on this type of treatment.

(ii) Does not require use of compressed air.

Disadvantages

(i) Space requirements are high.

(ii) Long retention times needed in order for bacterial action to be completed.

(iii) Shipboard movement affects the process.

(iv) Odorous and noxious gases produced.

Disadvantages (cont.)

(v) Anaerobic bacteria are more hazardous to humans than are the aerobic type.

(vi) Field tests have not shown efficient results even under good conditions.

(e) Electro-Chemical

This system has been designed to produce an effluent that will be equal to or better than standards of 50 mg/l B.O.D., 150 mg/l suspended solids and 240 coliform bacteria per 100 ml. Tests carried out by the U.S. Corps of Engineers on board a dredge confirmed the ability of this type of plant to meet these standards. Experience, however, is limited on this type of system.

The system accepts sewage, ground galley waste, wash water and laundry waste. The manufacturers claim that the above standards can readily be met or exceeded.

Advantages

(i) Automatic, capable of accepting all sewage and domestic waste and unaffected by greases, detergents and toxic materials, or hydraulic and biochemical loading.

(ii) Can operate satisfactorily in salt or fresh water and in heavy sea states.

(iii) Suitable for use on long voyages in waters where treatment is required.

Disadvantages

(i) Electrocoagulation (electrolytic) cell generates hydrogen and oxygen gases which could be hazardous if not efficiently ventilated.

(ii) Complex control system is required.

(iii) System is comparatively new and although a prototype has been operated and tested under shipboard conditions, data obtained from operating experience is limited.

(f) Separator-Chemical

This system has been designed to treat sewage only and to produce an effluent quality equal to or better than 50 mg/l B.O.D., 150 mg/l suspended solids and 1000 coliform bacteria per 100 ml. Manufacturer claims that these standards can be obtained but no shipboard trial data is available at this time. On the basis of the principles employed, it is thought that the system should be capable of obtaining the high effluent standards claimed.

Advantages and Disadvantages

Insufficient data available for an assessment.

(g) Electro-Mechanical

This system is designed to accept and treat sewage, galley and other wastes to a liquid effluent of a high standard.

Little data is available at this time but from the principles employed by the system, its efficiency, size and capacity are understood to be similar to those for the Electro-Chemical Treatment System.

Advantages and Disadvantages

Insufficient data available for any assessment of advantages and disadvantages, but these should be similar to those quoted for the Electro-Chemical Treatment System.

(h) Macerator-Chlorinator

This system is somewhat efficient with respect to the reduction of coliform content in the effluent, but there is little reduction of B.O.D. and suspended solids. The system is not intended for treatment of wastes other than human sewage, but will accept material from galley garbage grinders which have been provided with suitable grease traps.

Advantages

(i) Does not require retention for long periods, therefore units are relatively small and suitable for large complements.

(ii) Can be installed utilizing limited space.

(iii) Automatic and does not require constant surveillance.

Disadvantages

(i) Provides treatment to reduce coliform bacteria only; there is no reduction in suspended solids and only partial reduction in B.O.D.

(ii) Cannot be used in waters where strict water quality standards apply.

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(i) Vacuum Transportation

These systems are basically intended to be used in conjunction with a holding tank or storage system, air being used as the main medium for transporting the waste to the holding tank. By reducing the quantity of flushing water, the total volume of waste and water entering holding tank is reduced, thereby increasing the retention time for a given tank size. The contents of the holding tank may be chlorinated in order to reduce coliform bacteria, but there is no significant reduction in suspended solids or B.O.D. The system is primarily intended to receive sewage but can handle wastes from galley garbage grinders provided greasetraps are fitted.

Advantages

(i) Reduces sewage volume to holding tank and thereby increases retention time for a given tank size or reduces tank size for a given retention time.

(ii) Transportation piping can be of small diameter (approx.2") and can be installed around corners and obstacles and does not have to be sloped downwards.

(iii) System does not require constant surveillance.

(iv) System can be used in conjunction with treatment systems in which reduction in water content of influent is advantageous.

Disadvantages

(i) This system does not treat or improve the quality of the sewage.

(ii) Where discharge of holding tank contents to water is prohibited, or where strict water quality standards apply, holding tank must eventually be discharged to a shore facility.

(iii) Standard type toilet fixtures cannot be used.

(j) Heater Evaporative

These are designed to receive sewage only. The concentrated sludge removed from the evaporator tanks can be readily disposed of ashore, thereby eliminating the necessity for any discharge to the water. The U.S. Corps of Engineers reports that the system has given good results during a two year on-board trial period. No further information is available at this time but periodic performance tests conducted by the U.S. Environmental Protection Agency indicate that the system operates well within public health standards.

Advantages

(i) Particularly suitable for vessels which have critical space and weight constraints since volume and weight factors are reduced by a factor of at least 5 to 1 when compared with aerobic treatment systems.

(ii) Suitable for operation in areas where discharge of sewage is prohibited.

(iii) Suitable for long voyages in waters where treatment is required.

Disadvantages

(i) Periodic need for shore disposal of sludge.

(ii) Treats liquids and sewage only, impractical to evaporate other liquid wastes due to the large volumes of the latter and cannot handle solid galley wastes.

(iii) Creates pollution of the air.

(k) Boiler or Stack Evaporation

These systems were designed for use on towboats which are underway for extended periods of time. Information is limited and no operating test results are available. Due to the lack of complete test results no appraisal can be made of the efficiency of these systems but it is known that some difficulties were met during the initial phases and it is not yet certain that these have been overcome.

Advantages and Disadvantages

Cannot be assessed at this time due to lack of data but an obvious disadvantage is that the system can only be used when the ship's boilers or engines are at near maximum output.

3. Estimation of Capacities and Sizes

Capacities and sizes of all systems must depend upon the number of personnel on the ship, the volume of flushing material, the quantity of sewage created per person per day, the number of days the systems will be in use and the design of the systems themselves. Hence there will be a different figure on capacity and size for each ship, depending upon all of the above factors. In order to enable some kind of comparison to be made the following table has been drawn up for the conditions shown under the heading "Assumptions". However, it was not possible to make allowance for each individual manufacturer's design features and the results listed can be taken only as averages and approximations. The figures do not include space for servicing, piping or toilets.

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Assumptions

Number of personnel on board	=	25
Vol. of flush water & sewage per day for conventional systems	=	27.5 U.S. gallons per person
Vol. of flush water & sewage per day for vacuum transportation	=	7 U.S. gallons per person
Vol. of sewage & chemicals per day for recirculating systems	=	0.4 U.S. gallons per person

Retention times where appropriate are given individually in parentheses.

	Type of System	Approximate space requirement in cubic feet
(a)	Holding tank (sized for 10 days retention)	1200
(b)	Recirculating (sized for 90 days retention)	500
(c)	Vacuum Transportation (sized for 10 days retention)	300
(d)	Aerobic (continuous treatment)	500
(e)	Anaerobic (continuous treatment)	800
(f)	Electro-Chemical (continuous treatment)	200
(g)	Separator-Chemical (continuous treatment)	200
(h)	Electro-Mechanical (continuous treatment)	200
(i)	Macerator Chlorinator (continuous treatment)	100
(j)	Heater Evaporator (continuous treatment)	100
(k)	Boiler or Stack Evaporator (continuous treatment)	100

These space requirements could be further reduced for most of the above systems if they were designed to use a minimum of flush water, but at this time there has been no research in this respect except in the case of the vacuum transportation system.

4. Estimation of Capital Costs

There is a wide variation in the possible capital costs for sewage treatment or retention systems due to the need to take into account factors such as:-

(a) whether the ship is new or existing,

(b) whether passenger or cargo type,

(c) number of personnel,

(d) efficiency of treatment required,

(e) percentage of time system will be in use,

(f) space requirements,

(g) location of unit,

(h) piping layout and disposition of toilets,

(i) routeing of vessel.

The systems themselves vary considerably in cost, and as manufacturers can not readily quote costs on a general basis because of the variables mentioned above it has not been possible to obtain accurate figures for all types. For example, some vessels do not have the time available for the frequent pumping out of retention systems and therefore will require a proportionately larger holding tank, a more costly waste concentration system, or some form of on-board treatment. Because of this wide variation in cost data and the difference in cost of treatment and retention systems, it is difficult to arrive at any initial cost figure either per man or per vessel.

It does appear, however, that the cost per man of a retention system generally increases with the number of complement served and the cost per man of a treatment system generally decreases with the number served. The cross-over point occuring at a complement of about 50 gives some guidance to shipowners as to what system to consider but this must be qualified by the other factors listed above, particularly the percentage of time during which the system will be in use.

Retention systems have varied in installed cost from $600 to $2500 per person. A U.S. Navy development prediction of initial costs of 12 treatment systems of 175 man capacity averaged about $600 per person. For cargo vessels an average of installed costs for both treatment and retention systems gives $1225 per person for large vessels, and $800 per person for smaller vessels. For very small vessels an average cost in Canada has been found to be $200.

For the purposes of this study it was decided to use, for estimating capital cost, a figure of $1225 per person for non-passenger vessels with complements of more than 40, $800 for such vessels with complements of from 5 to 40 and $200 for a complement of less than 5 and these result in the table given below.

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INITIAL INSTALLED COST ESTIMATES FOR NON-PASSENGER VESSELS

	Crew Size	Cost per Person in Dollars	Cost per Vessel in Dollars
Small Fishing Boats	3	200	600
Work Boats	6	800	4800
Tugs and Towboats	8	800	6400
Survey Ships	10	800	8000
Small Cargo Vessels	12	800	9600
Marine Drilling Rigs	30	800	24000
Offshore Construction Barges	40	800	32000
Large Cargo Vessels	45	1225	55000

There is even less information available re the capital costs of sewage treatment and retention systems in passenger vessels but, according to estimates provided by the United Kingdom, for a typical large passenger ship with a complement of 3000, the total costs of plants and their installation range from approximately $250,000 for untreated retention for a very limited period of time, to $1,000,000 for a continuous treatment system.

5. Annual Operating Costs

Annual vessel costs incurred will include the operation and maintenance cost of retention or treatment equipment, cost of chemicals and other additives, fees for holding tank pump-out and cleaning, and costs of equipment repair and replacement. Aditionally, with commercial vessels, there is cost associated with loss of revenue-producing time and cost of ship movements that may be involved in discharging retained wastes.

Annual operating costs are subject to wide variations. For an on-board treatment plant that performs with complete reliability under automatic control the cost will be only that of the power and chemicals required. Yet if frequent breakdowns or malfunctions necessitate repairs, maintenance, and parts, or if additional personnel is required aboard to operate the equipment, the cost can be very high. U.S. Navy projections on ships with a complement of 175 for annual operating costs are about $52 per man year.

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For recirculating toilets, supplemented by a retention tank, the cost of handling retained waste has been found to average about 7 cents per gallon. Assuming a body waste dilution rate of 27.5 gallons per man per day, the total retained waste per man per year would be 27.5 x 365 or 10,038 gallons. Multiplying this volume by 7 cents per gallon gives a figure of about $700 per man year. But if a recirculating system without a retention tank is used, then, because of the reduced volume, the figure might go as low as $16 per man year.

With such a wide variation in potential operating cost it was thought preferable to assume a maximum estimate; hence a charge of $700 per man year has been used for all non-passenger vessels, recognizing that this has a potential variation of from 5% to 100%, depending upon the system used.

The tables below show the results using $700 per man year for non-passenger vessels and figures supplied by the United Kingdom for passenger vessels, taking into account the amount of time spent in waters in which treatment or retention is required for non-passenger vessels, and the type of equipment for passenger vessels.

ANNUAL OPERATING COST ESTIMATES FOR NON-PASSENGER VESSELS

	Crew Size	% Use Restricted Water	Maximum Cost per vessel per year in dollars
Small Fishing Boats	2.28	11.0	175
Work Boats	6	33.3	1,400
Tugs and Towboats	8	50.0	2,800
Survey Ships	10	40.0	2,800
Small Cargo Vessels	12	25.0	2,100
Marine Drilling Rigs	30	100.0	21,000
Offshore Construction Barges	40	50.0	14,000
Large Cargo Vessels	45	33.3	10,500

ANNUAL OPERATING COST ESTIMATES FOR PASSENGER VESSELS

	Cost per Vessel per year in dollars	Type of System
Passenger Ship with a complement of 3000	250 to 300	Non treatment
"	1700 to 5000	Biological/Biochemical
"	70,000	Chemical treatment

6. <u>Installation Feasibility for Existing Ships</u>

The problem of installing new equipment in an existing vessel is considerably greater than that for a new design where it can be worked into the initial weight-space-stability balance. In an older vessel there can be extensive alterations required to route the sanitary system piping to the new equipment and to connect needed power and services.

Space and deadweight capacity are always at a premium on board ship and it is advisable to install in existing ships those systems with minimum weight and space requirements. The routeing of the vessel will also affect considerably the choice of treatment or retention system and hence have a direct bearing on the cost of the installation. Many conversions of existing ships have taken place, although the cost has sometimes been very high. In the case of existing non-passenger ships with relatively small crew numbers, it would appear to be technically feasible to install sewage treatment or retention systems to meet the strictest standards and for indefinite times. The cost of doing this, however, could in some cases be so high as to seriously affect the economics of operation. Accordingly, in such instances, consideration may have to be given to some form of relaxation based on the age of the vessel and its expectation of useful life.

In the case of existing ships carrying less than 50 persons a simple retention system would appear to be the easiest and most economical to install, provided the retention time was not excessive. For ships carrying over that number or where retention times were excessive consideration would have to be given to a flow through overboard discharge system provided the ship will be operating in waters where an overboard discharge is allowed. If overboard discharge is not allowed then ships with large complements or excessive retention times would best be served by recirculating, evaporating or incinerating systems.

To sum up, it is considered that existing cargo ships can safely, and without undue difficulty, be fitted with high standard sewage treatment or retention systems for use in all waters of the world and that the cost will sometimes be high but not prohibitive. In the case of existing passenger ships or other ships with large complements the feasibility, from the points of view of safety, practical considerations and cost, must depend upon the routeing, the time in port and the severity of the sewage effluent standards to be met. In certain cases it would appear that, at the present stage of technical development, such conversions would not be feasible for the vast majority of existing passenger ships.

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7. Sewage Discharge Standards

(1) The standards used to measure the quality of sewage effluent fall into three categories as follows:-

(a) Disease bearing characteristics

All sewage contains a type of bacteria produced within the animal known as coliforms which are usually harmless. However, disease bearing bacteria such as typhus can appear in conjunction with the harmless body coliforms and the possibility of these being present in the sewage effluent is a function of the total number of coliforms present per unit volume of sewage. A standard for sewage effluent therefore must include a count of the number of coliforms present per unit volume. The coliform count is determined by filtering the sample, placing the filter in a media and incubating for 24 hrs. The coliform colonies may then be counted.

(b) Ability to deprive receiving waters of oxygen

The ability of the sewage to absorb oxygen from the water is known as the Biochemical Oxygen Demand (B.O.D.) Fish and vegetable life normally occurring in the water require oxygen to live and any extraneous substance which absorbs oxygen from the water reduces that available for this normal life. If the oxygen content of the water is reduced to very small amounts then all normal marine life will disappear and be replaced by types of vegetation and bacteria that exist without oxygen. This creates anaerobic conditions with the production of methane, hydrogen sulphide and other undesirable chemicals. B.O.D. for a sample of sewage is measured by testing the effect of the sewage over a period of time on a sample of water of known oxygen content and is measured in milligrams of oxygen absorbed per litre of sample.

(c) Solid content

The principal effect of suspended solids is to destroy the aesthetic qualities of the water but they can also contribute to the deposit of sludge when large quantities are present. It is measured in milligrams per litre by passing samples of the sewage through a filter and then weighing the residues.

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(2) The appropriate standards for the above categories are more specifically defined as follows:-

(a) Coliforms

Coliforms, measured in number per 100 millilitres, are the aerobic and facultative anaerobic, gram-negative, non-spore forming, rod shaped bacteria that

(i) in the Tube-Dilution test, will ferment lactose with gas formation within 48 hours of incubation at 35°C., or

(ii) in the Standard Membrane Filter Technique will produce a dark colony of a generally purplish green colour with a metallic sheen on M-Endo Broth or Agar within 24 hours of incubation at 35°C.

(b) Biochemical Oxygen Demand (B.O.D.)

Biochemical Oxygen Demand (B.O.D.) is an expression of the oxygen, measured in milligrams per litre, required by the bacteria while stabilizing the organic matter in a sample of sewage under aerobic conditions over a period of five days at 20°C.

(c) Suspended Solids

Suspended Solids, measured in milligrams per litre, are the solids that either float on the surface of, or are in suspension in, water, wastewater or other liquids, and which are largely removable by laboratory filtering.

8. Various Regulatory Measures

(1) Various regulatory and environmental authorities have suggested or put into practice sewage discharge standards that have incorporated all or some of the discharge standards described in the preceding section. These regulatory measures have varied in degree of severity depending upon the particular needs of the locality for which the protection is required. They have usually required that there be no discharge of sewage within certain waters such as those used for drinking or recreational purposes but the proposals have usually not been so rigorous for waters not used for those purposes. However, they have always been designed to preclude a build-up of pollution in the surrounding water.

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Listed below are four different discharge standards, in decreasing order of severity, which to this date have either been suggested or put into effect by regulatory or environmental authorities:-

	Maximum Coliforms cols. per 100/ml.	Maximum B.O.D. mg. per l	Maximum Suspended Solids mg. per l
A.	No discharge	No discharge	No discharge
B.	0	15	15
C.	240	100	150
D.	240	60% reduction	75% reduction
E.	240	85% reduction	90% reduction
F.	1000	100	150
G.	1000	50	150
H.	1000	No limit	No limit

(2) As technical progress continues it is probable that the highest of the above standards will eventually be met by flow-through sewage treatment systems which will permit the discharge overboard of high quality effluent. Present experience indicates, however, that the higher standards can only be met on a continuous basis at this time by equipment that treats the sewage without discharging it into the water and the most successful systems of this type to date are of the recirculating, incinerating and evaporative types.

Equipment that discharges the sewage effluent overboard on a continuous basis can, at the present state of technology, meet only the lower standards quoted above.

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APPENDIX.

Summary of Study VIII (Sewage Treatment Systems)

Eleven basic methods of treating shipboard sewage have been evaluated and estimates made of capacity, costs and installation feasibility. Various sewage quality criteria and standards are also described. The study reveals the difficulty of estimating on a general basis the cost requirements of sewage treatment systems due to the large number of variables that can apply in the case of each ship. Some systems such as retention, recirculating, aerobic and macerator-chlorinator systems already have an extensive background of use with the recirculating system being generally the most effective when all variables are taken into account. The remaining systems show promise with the evaporative and vacuum transport types appearing more suitable for short term development.

The cost of installing any of these systems in an existing ship is considerably more than it would be for a new ship. In the case of large passenger ships and other ships with large complements, installation on existing ships would probably not be economically feasible. The initial installed capital cost on a large cargo vessel averages $55,000 with an annual operating cost up to $10,000 depending on the variables. For large passenger vessels a capital installed cost varies from $250,000 to $1,000,000 with operating costs up to $70,000 per year.

To sum up, cargo ships could, without undue difficulty, be fitted with sewage treatment systems suitable for use in all waters, but the cost would be much higher for existing vessels. The feasibility of installation of such systems in large passenger ships depends upon the routing, time in port and the required effluent standards. At the present stage of technical development, such conversions would not be economically feasible for the vast majority of existing passenger ships.