DEVELOPMENTS IN SEWAGE POLLUTION CONTROL

BY

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ABSTRACT

It is MOD policy that H.M. vessels should be equipped, where practicable, to meet IMO regulations for sewage discharge. Biological sewage treatment plants are seen as offering the best solution. Trials on a biological plant in H.M.S. *Southampton* have now been successfully concluded. The plant produced an effluent well within IMO standards during a one month period while the ship was fully operational at sea. It is the intention that most other biological plants in the Fleet will now be upgraded to the standard of the *Southampton* plant. For future ships an entirely new treatment plant is being developed which promises to be more compact and efficient than earlier types. Testing of a development plant at a new shore test facility at H.M.S. *Sultan* is in progress and an improved BSTP should be available for service within some two years.

Introduction

Over the past 15 years there has been a growing concern about the effects of pollution on the marine environment. A set of regulations controlling the levels of pollution from ships was first agreed at the London Conference of the International Maritime Organization (IMO) in 1973. These, together with their 1978 Protocol, are known collectively as MARPOL 73/78. Five groups of pollutants were identified and specific regulations were drafted for each type under separate Annexes to MARPOL 73/78. These may be summarized as follows:

Annex I	Regulations for the prevention of pollution by oil.
Annex II	Regulations for the prevention of pollution by noxious liquid substances carried in bulk.
Annex III	Regulations for the prevention of pollution by harmful substances carried by sea in packaged forms.
Annex IV	Regulations for the prevention of pollution by sewage from ships.
Annex V	Regulations for the prevention of pollution by garbage from ships.

Annexes I and II are already in force. Annexes III, IV and V are defined as 'optional' and as such will only come into force one year after they have been ratified by at least 15 countries representing 50% of the world's shipping tonnage. To date, some 28 countries have ratified the sewage regulations under Annex IV but these only represent 43% of the world shipping tonnage. It is interesting to note that the U.K. is one of the countries yet to sign. It seems unlikely that the required 50% figure will be reached before the middle of the 1990s.

Unfortunately, the delay in implementing MARPOL 73/78 only increases the likelihood of individual nations enforcing their own regulations. Local controls on the discharge of sewage are already enforced in the U.S.A., the Canadian Great Lakes, the Baltic, the Black Sea and Japan. Already, some countries will refuse entry or allocate poor berths to visiting ships if not satisfied that adequate pollution control equipment is fitted. Such national restrictions are likely to become more widespread over the next few years.

In the U.K., legislation controlling sewage pollution from ships is contained under Part II of the Control of Pollution Act 1974 (COPA 74). The controls are operated by local Port Authorities so that the specific restrictions and the rigour of their enforcement vary from port to port. The U.K. is also bound by EEC Directives which place controls on the levels of sewage pollution in bathing waters.

Although government-owned vessels are exempt from IMO regulations and also enjoy Crown Exemption from COPA 74, they are expected to abide by them as far as is operationally practicable. In addition, exemption from the regulations of other countries cannot be assumed and in most cases is unlikely to be granted. Therefore, it is MOD policy that H.M. vessels should be equipped to meet IMO requirements wherever possible.

It is against this background that DGME (the department of Director General Marine Engineering in MOD) embarked upon an extensive sewage treatment plant development programme a little over three years ago.

IMO Regulations

Under IMO regulations the discharge of sewage will only be allowed if:

(*a*) (within 4 miles of the coast) An IMO approved sewage treatment plant is in operation.

(*b*) (between 4 and 12 miles of the coast) An IMO approved system to comminute and disinfect the sewage is in operation.

Beyond these limits it will be permissible for ships to discharge raw sewage provided they are making at least 4 knots. The regulations will apply to all vessels of 200 gross tonnes and above, and also to vessels that carry 10 or more persons. Vessels under construction when Annex IV comes into force will be required to comply with the regulations. Existing vessels will be given a further 10 year period in which to fit the required pollution control equipment.

Types of Sewage Treatment Plants in Service

There are three types of sewage treatment plant in service with H.M. vessels. These are:

(*a*) Biological sewage treatment plants (BSTP).

(*b*) Solid separation treatment plants (SSTP).

(*c*) Collect, hold and transfer systems (CHT), with either gravity or vacuum collection systems.

Historically, the BSTPs were the first to be used in service. These are fitted to the early Type 42s, the Batch I Type 22s, the MCMVs, the ISLAND and CASTLE Classes, survey ships, the CVS and RFAs. For a number of reasons, many of these plants were found to be unsatisfactory in service, and from the late 1970s vessels such as the Type 42s (09–14), *Challenger,* and the Hong Kong Patrol Vessels, were fitted with SSTPs. At the same time several older vessels were retro-fitted with SSTPs. These included the Batch III LEANDERS and H.M.Y. *Britannia.* Many smaller vessels are fitted with simple gravity CHT systems normally with a hold time of only 24 hours.

The present policy is to fit new build ships with vacuum CHTs. These systems are fitted to the Batch II Type 22s, the Batch I Type 23s and Single Role Mine Hunters.

Biological Sewage Treatment Plants

In all there are some 80 BSTPs in service. Theoretically, this type of plant should allow ships to operate for long periods without the need for shore reception facilities. In practice they have not operated satisfactorily for the following reasons:

(*a*) The process depends upon effective reduction of the sewage by bacteria in the main aeration tank. This process is very sensitive to:
- (*i*) Changes in the salinity of the flush water.
- (*ii*) High hydraulic loads caused by defective toilet flushing valves or leaking tank-cleaning spray cross-connection valves.
- (*iii*) Variations in the load cycle imposed by the operating pattern of the ship. Low loads are particularly detrimental as the bacterial population necessary for aerobic digestion of the sewage cannot be sustained.
- (*iv*) Excessive use of detergents and cleaning agents which destroy the bacterial population.

(*b*) Being continuous flow processes there is no control over the residence time in each tank. This can result in incomplete processing of the sewage and carry-over of solids.

(*c*) Ship motions affect the settling process.

Solid Separation Treatment Plants

This type of plant has the advantage that it is available on demand and can be shut down when the ship is outside controlled waters. However, these plants have not been entirely satisfactory in service for the following reasons:

(*a*) The Biological Oxygen Demand (BOD) level of the discharge does not meet the IMO standard[1], mainly because of high solids content in the effluent.

(*b*) The filters have proved to be particularly troublesome. They block frequently and require considerable and unpleasant maintenance.

(*c*) The plants have a relatively short holding time of only 5 to 7 days.

(*d*) The plants use a lot of disinfectant (15 lb/day).

These plants are no longer being considered for future ships. However, there is an ongoing development programme aimed at improving the performance of the plants already in service. The main areas under consideration are as follows:

(*a*) *Filters.* Minor Trials of improved filters are in progress. The feasibility of installing these in a duplex filter arrangement outside the tank is also being investigated. This would improve the maintainability of the plants considerably.

(*b*) *Chlorination Method.* Calcium hypochlorite dosing is used in the present system. This is a hazardous chemical and alternative methods of disinfection (e.g. electrochlorination) are under consideration.

Collect, Hold and Transfer Systems

There are some 55 CHT systems in service. The majority are of the gravity collect type and are fitted to smaller ships. An Evac (Electrolux) vacuum CHT system is undergoing trials at sea in H.M.S. *Juno* and shore trials on an Evac vacuum CHT system have recently been completed. No major problems were encountered during these trials and vacuum systems are now being fitted to the larger new build ships (Evac will be fitted to the Type 22s (10 onwards) and the SRMH, and Electrolux will be fitted to the Type 23s).

The main problem with CHT systems is their limited hold time of 5 to 7 days. This in turn leads to the requirement for costly sewage reception facilities in the Naval Bases and can lead to problems when ships visit or operate in clean areas. For destroyers and frigates and above CHT is seen as providing an interim solution only until a fully developed treatment plant becomes available.

Development Activities

DGME is concentrating sewage plant development work on two fronts. Firstly, efforts have been directed at producing a modification package for existing biological plants so that they may be brought up to IMO performance standards. The after plant in H.M.S. *Southampton* was used as the lead plant in this programme. The second approach has been to design and develop an entirely new treatment plant for future fitting. A pilot plant has been on trials at H.M.S. *Sultan* since March 1987.

Sewage Treatment Plant Modifications in H.M.S. Southampton

The original manufacturer of *Southampton*'s plant, Kelston Engineering, has been out of business for some time—an all too familiar story in the marine sewage industry. Hamworthy Engineering Ltd., manufacturers of a successful range of commercial biological plants, were selected to carry out design and modification work in support of the project. Plant performance testing, in accordance with IMO specifications, was conducted by the Institute of Naval Medicine (INM) during periods when the ship was at sea. To INM's great credit they managed to transport themselves and their 'mobile' laboratory equipment to almost every corner of the globe in pursuit of the elusive IMO certificate. On one occasion the INM team were to be found in Port Stanley ready to join *Southampton* while their lab equipment was lost somewhere at Ascension. Fortunately, after much frantic signalling the equipment was located and continued its journey to the ship in time for the trial.

Development work on H.M.S. *Southampton's* after plant was carried out in 5 separate stages over a two year period, finally completing with successful trials during 1986. Each stage involved a series of modifications followed by a minimum 10 day trial while the ship was at sea. Several weaknesses in the original plant design were identified:

(*a*) Poor aeration performance.

(*b*) Inadequate sewage retention times in the main aeration tank and the settlement tank, resulting in inadequate processing.

(*c*) No reliable chlorination system.

To resolve these problems the first set of modifications included:

(*a*) Ceramic fine bubble air diffusers were fitted to the aeration tank to improve oxygen transfer efficiency.

(*b*) The transfer airlifts between aeration tank and settlement tank were removed and replaced by a simple flow-over weir. This also allowed the liquid level in the aeration tank to be raised, thereby improving retention time.

(*c*) The retention time in the settlement tank was increased by fitting a 'hat box' on top of the tank, thereby increasing its volume.

(*d*) A surface 'skimmer box' with return connection to the aeration tank was fitted to the settlement tank. This collects floating sludge and foam for return via an air lift to the main aeration tank.

(*e*) The calcium hypochlorite dispenser was replaced by a simple 'Sanuril' waste water chlorinator.

High effluent suspended solids levels apparent in the results indicated poor settlement efficiency. It was therefore necessary to make extensive modifications to the settlement tank. The main changes were:

(*a*) The settlement tank cross-sectional area was doubled to reduce the upward flow velocity through the tank and hence encourage more efficient settlement.

(*b*) The settlement tank shape was changed from an assymetrical shape to a symmetrical inverted pyramid with 60° sides. This encourages the removal of sludge from the tank sides. If allowed to accumulate such sludge becomes anaerobic and releases bubbles of nitrogen which interfere with the settlement process.

(*c*) To enhance sludge removal from the tank sides, a motor-driven scraper was fitted to the settlement tank. This comprises a chain, suspended from a rotating arm, which is dragged around the tank sides.

Following these modifications further trials were carried out over a one month period while H.M.S. *Southampton* was operating in the Gulf. Ninety-eight effluent samples were analysed by the INM team during the trial and the results achieved are shown in TABLE I.

TABLE I—*Results from the trial in H.M.S. Southampton*

Variable	*H.M.S. Southampton (geometric mean of 40 samples)*	*IMO requirement (geometric mean of 40 samples)*
BOD_5 mg/l	12	50
Suspended solids mg/l	25	100
Coliform count No per 100 ml	6	250
Residual chlorine mg/l	4	5

As can be seen, the results were well within IMO standards. A formal application is presently being made to the Department of Transport for the award of an IMO certificate. At the same time design proposals are being sought to modify the biological plants in the Type 22s and other plants in the Type 42s. It is intended to carry out similar exercises for the CVS, MCMVs and possibly certain RFAs. These design studies will allow A&A packages to be defined. Assuming that the As and As attract sufficient priority and are approved, it is hoped that the majority of our ships will be equipped to IMO standards by the latter half of the 1990s.

Development Plant for Future Ships

It has already been explained that the VCHT systems being fitted to the Type 23s and Type 22s only provide a 5 day holding time. In certain cases this could limit the operations of these vessels since, when in controlled waters, they will need access to sewage reception facilities every few days. For future ships, the aim has been to develop a plant that will allow ships to operate for extended periods (one month or more) without need to discharge sewage sludge. Biological treatment plants are seen as having two significant advantages over other types:

(*a*) They have the potential to meet full IMO standards and indeed any more stringent requirements that may be enforced in the future.

(*b*) They process the bulk of the sewage leaving relatively small volumes of sewage that can be stored on board for long periods (typically 1 to 3 months).

Earlier attempts to develop an improved BSTP were constrained by the following deficiencies:

(*a*) There had been no attempt to control the process precisely, i.e. by strict batching.

(*b*) The plants did not possess a fully engineered control system associated with (*a*) above.

(*c*) There had been no structured development programme to determine best plant operating characteristics, e.g.:

- optimum batch size.
- optimum treatment time.
- optimum activated sludge concentration.
- optimum level of dissolved oxygen.
- optimum system configuration.
- optimum settling/filtration methods.

(*d*) There had not been an effective Shore Test Facility.

Each of these deficiencies was addressed in the design and development of the new plant. The various known operating problems also had to be solved. The most significant of these were:

(*a*) Sensitivity to changes in the salinity of flush water which is a major limitation of existing biological plants. The resulting change in osmotic pressure destroys micro-organisms essential for efficient plant operation. To overcome this, the plant was designed to process sewage from a low volume vacuum sewage collection system using fresh water only.

(*b*) Existing plant designs rely on gravity settlement of solids for effluent clarification. To achieve more effective clarification, filters were incorporated. (A number of different filters are to be tested).

A significant consideration in the proposed new plant concept is that the collected sewage would be some 20 times more concentrated than usual domestic sewage and established design criteria were not reliable.

It was important therefore to produce a pilot plant (FIGS. 1 and 2) of flexible design capable of accommodating changes to tank configurations, process sequences and control logic which would allow plant optimization during trials. Plastics were selected for the tanks and pipework to allow inexpensive modifications to be made easily. Control flexibility was achieved by selecting a microprocessor-based system which would allow control logic to be altered cheaply and easily through modifications to control algorithms programmed onto EPROMs (erasable, programmable, read only memories).

FIG. 1—THE PILOT PLANT INSIDE ITS ISO CONTAINER

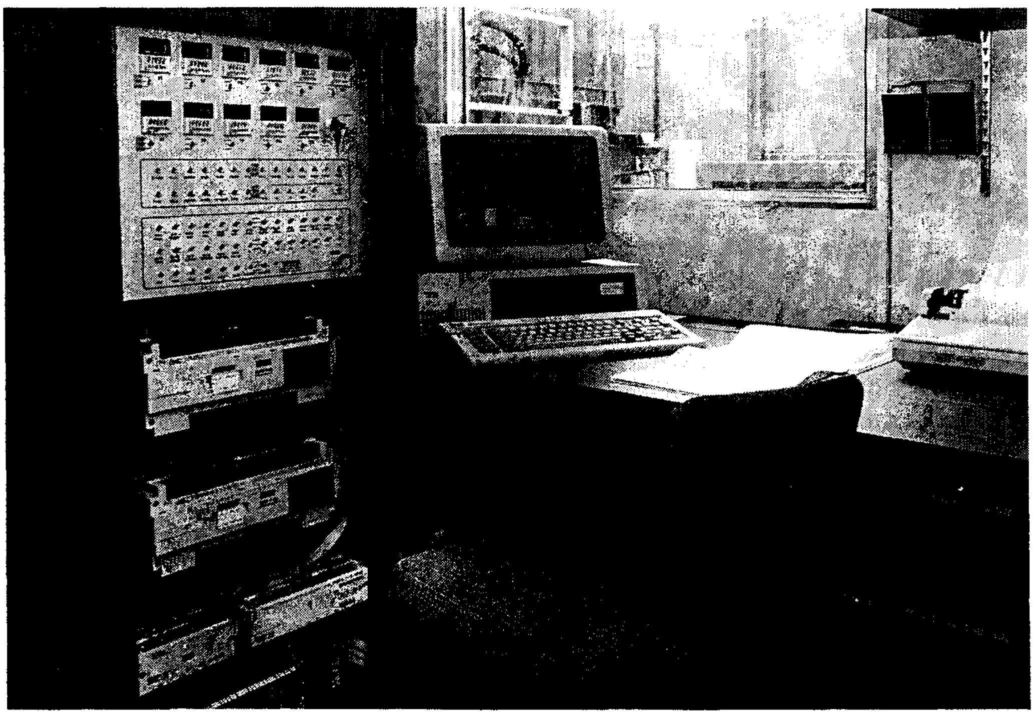

FIG. 2—PILOT PLANT CONTROL CABIN SHOWING THE PLC AND DATA LOGGER

Perhaps the key element in the project has been the setting up of a purpose built shore test facility for sewage plants. Experience in H.M.S. *Southampton* had highlighted the costs and difficulties of running sewage plant trials in an operational warship. However, there were significant problems to be overcome. The plant would need 100 man's worth (one cubic metre) of sewage each day—where could we plumb into such a supply and would anyone actually welcome a sewage test facility on their doorstep? A number of civil engineering contractors were approached with a view to siting the plant at one of their workers' encampments. Although several possible sites were identified these were generally not ideal. Fortunately, H.M.S. *Sultan* agreed to offer their facilities. Detailed planning for the test facility began during the early part of 1986. By the end of that year, due in great measure to the support of H.M.S. *Sultan,* the PSA and the various contractors involved, the test facility was in operation. It has been sited on the eastern boundary of H.M.S. *Sultan* and takes sewage from three 60 man accommodation blocks (FIG. 3).

FIG. 3—AERIAL VIEW OF THE SEWAGE TREATMENT PLANT TRIALS FACILITY AT H.M.S. 'SULTAN'.
FROM LEFT TO RIGHT:
'SULTAN' ACCOMMODATION BLOCK
AUXILIARY MACHINERY AND COLLECTION PLANT ACOUSTIC ENCLOSURE
AIR OUTLET WITH FILTRATION EQUIPMENT
END OF INSTRUMENTATION CABIN
ISO CONTAINER ON ITS ROLLING PLATFORM

Existing gravity toilets and urinals were replaced by standard Evac vacuum units. Two existing gravity toilets were left in each block in case of vacuum failure. Two inch bore plastic pipes connected the toilet blocks to the Evac collection system at the test site. An important aspect of the design was a special acoustic housing for the auxiliary machinery located near the accommodation blocks.

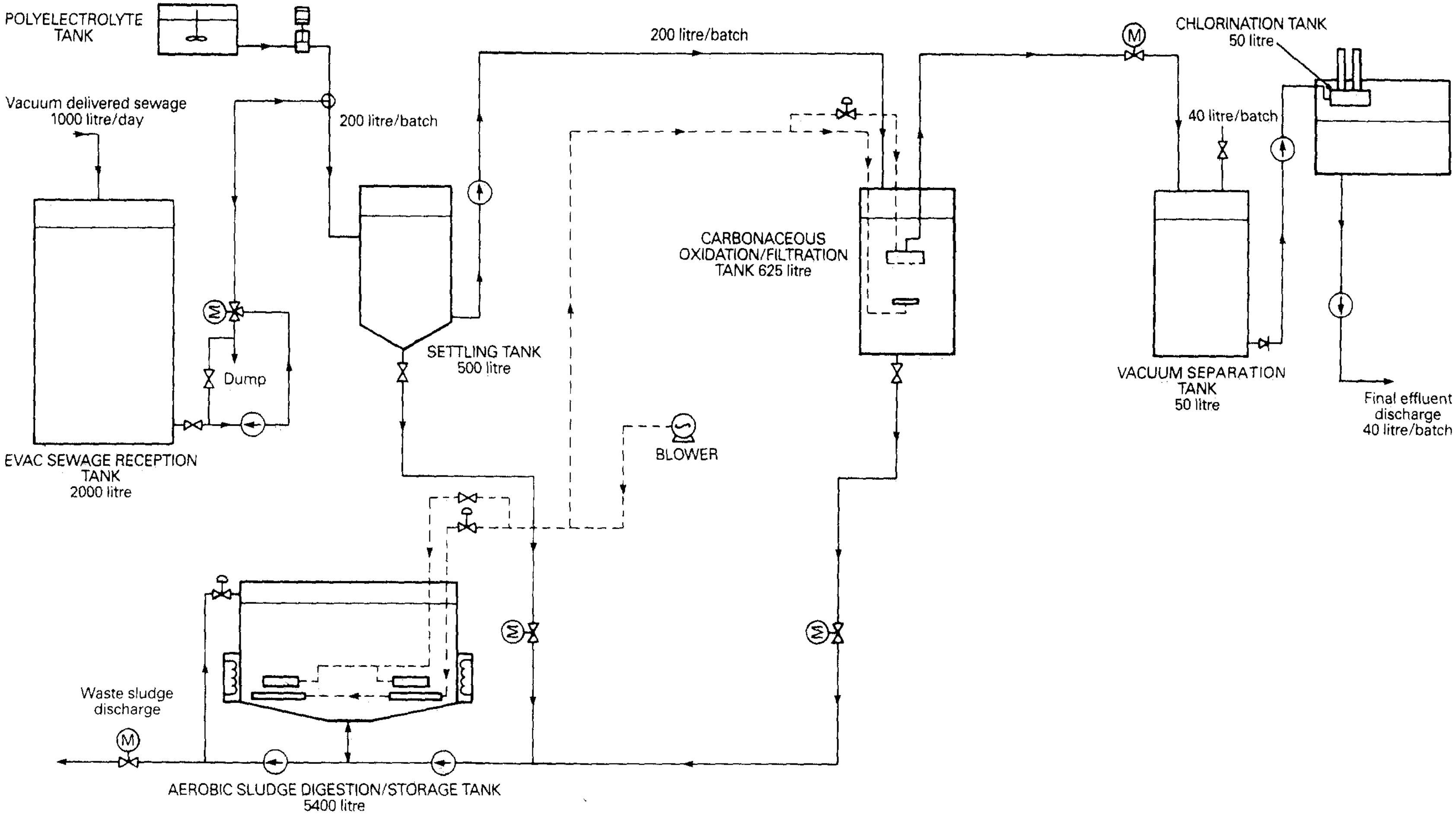

FIG. 4—THE PILOT MARINE SEWAGE TREATMENT PLANT PROCESS

In order to simulate shipboard conditions as closely as possible the test treatment plant was mounted on a hydraulically operated pitch and roll frame. It is intended that this will be used during the final phase of the trials to test the sensitivity of the treatment processes to the disturbances caused by ship motions.

Plant Process Description

A schematic of the pilot plant process is shown in FIG. 4. The process may be described as follows:

(*a*) Sewage is transferred in batches from the Evac reception tank to the settling tanks approximately every 6 hours. (N.B. The batch time is varied automatically depending on plant load). The settlement of solids is encouraged by injecting a polyelectrolyte at this stage. By removing solids, the BOD loading on the remainder of the plant is significantly reduced.

(*b*) Before receipt of sewage from the reception tank, a batch of clarified liquid is transferred from the settlement tank to the oxidation, filtration tank.

(*c*) Having been aerated in the aeration/filtration tank, small batches of liquid will be drawn into a vacuum separation tank via filters every 2 hours (this period is adjustable). A 5 second air back-wash is applied to the filter every 2 to 5 minutes.

(*d*) Batches of liquid are transferred from the vacuum tank to the chlorine tank every 2 hours immediately before the next batch is received from the aeration tank.

(*e*) The chlorine contact tank holds batches of liquid for 2 hours, allowing more than adequate contact time, before effluent is discharged overboard. Chlorination is achieved using a Sanuril tablet dispenser.

(*f*) Sludge is automatically withdrawn from the settling tank and aeration tank and transferred to a heated sludge digestion tank. This tank has the capacity to hold the sludge in a stable condition for at least 20 days before discharge outside controlled waters is necessary.

Trials have now been in progress for about 8 months and development work is concentrating on two main areas:

(*a*) Optimization of plant loading to suit the high strength vacuum collected sewage.

(*b*) Development and optimization of a range of sewage filters.

Conclusions

R.N. experience indicates that all sewage treatment plants presently available are unsatisfactory and, without significant modifications to certain biological plants, cannot be relied upon to produce an effluent that will consistently meet the requisite standards. It is MOD policy that R.N. vessels will be equipped with plants that will conform with the relevant standards. As a result an extensive development and modification programme has been set in hand. Successful trials on board H.M.S. *Southampton* have led to a modification package for biological plants and a facility has been built at H.M.S. *Sultan* to develop a new biological plant for R.N. applications. Results from the *Sultan* facility are encouraging and it is planned that a proven prototype plant will be available for servicing within two years.

Reference

1. Morris, J. E. W., Marsden, P. H. and Bishop, A.: Sewage treatment plants; *Journal of Naval Engineering*, vol. 28, no. 2, June 1984, pp. 254–263.