"The optimisation of membrane bioreactor technology for use in the treatment of marine wastewater"

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Summary:

The Hamworthy Group has been a major supplier of treatment systems for wastewater generated on ships for more than 25 years. A continuing product development programme, directed by the demands of the marine market, and by the availability of new technologies, has led to significant advances in the standards of waste water treatment that can be achieved.

This paper describes the development of a combined high rate bioreactor and membrane separation system, capable of handling a range of alternative profiles of wastewater input, and of producing consistent high quality effluent. A programme of conversion for an in-service cruise ship is described, with comments on operational experience.

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1. Introduction

I expect that most of the people here today will be aware of the Hamworthy Group as a supplier of marine equipment. The group has a multi-product capability, dedicated to the supply of specialist equipment for the marine industry. Many of our product groups not only hold positions of technical leadership in their respective market sectors, but are also based on strong historic sales figures and wide application experience. This is particularly the case for wastewater treatment systems, where we have supplied more than 6000 systems over a twenty-five year period.
Our close contacts with operators of wastewater treatment systems, and the builders and repairers of ships, mean that we are not only aware of the way the equipment is specified to work, but also the real conditions that exist after extended operation. Hamworthy have sought to design equipment that gives high values to ease of operation, product maintainability and consistent achievement of the required performance.

In looking for the optimum solution to a system design problem we are not constrained by a company commitment to any particular technology. We are able to assess the widest possible range of available techniques, and choose those that are the most appropriate solution to the customer need. There is of course a high degree of expertise within the company in the handling and treating of wastewater, supported by academic and commercial in depth specialist knowledge where required.

2. Key agents for change

For wastewater discharges there are a number of alternative standards that are either in force or under discussion. A complete discussion of these alternatives would be a subject for a separate paper, however it is apparent that conformance to IMO / USCG historic standards for treated sewage (black water) is not sufficient to meet the expectations of those responsible for regulating some coastal waters.
The demand for cruise ship visits to areas of great natural beauty and plentiful wild life has produced a heightened sensitivity to waste discharges. Monitoring of discharge water quality, and enforcement and penalties in the event of non-conformance to regulations is now the norm for the Alaskan area. We can expect similar action in other coastal waters where regional and national authorities have strong concerns for the protection of the marine environment.
Conformance to the regulatory requirements is not only driven by the penalties that may be imposed by authorities, but also by the strong negative marketing image of publicity following the identification of unacceptable discharges.

3. Definition of the waste water problem

One difficulty in establishing a suitable design of treatment system is to establish a clear definition of the wastewater to be treated. Ideally the treatment system should handle the aggregate of black water, sanitary grey water, laundry water and water from galleys, however for some of the waste streams the quality and quantity of the water can vary considerably depending on the system design. Each waste water system needs individual assessment to determine the necessary treatment processes, pre-treatment may be necessary for some waste streams, ie fat and grease removal from galley waste water. Consideration needs to be given to the strength of the waste, to at least define the level of waste degradation and solids removal necessary to meet the required discharge standards.
We have chosen to design the basic process to meet the US standards for discharge of treated waters to inland waters, given in the Code of Federal Regulations Title 40 Part 133.

	Units	IMO	USCG	40 CFR 133
		10 day ave	10 day ave	30 day ave
Suspended Solids	mg/l	50 (100 at sea)	150	30
BOD_5	mg/l	50	Not required	30
Faecal Coliform	count/100ml	250	200	20 (see note)
pH		Not required	Not required	6.0 to 9.0
Chlorine	mg/l	As low as practicable	Not required	10.0 (see note)

Note: Test methods and averages vary in definition dependent upon test authority, Faecal Coliform and Chlorine limits are not part of 40 CFR 133, but additional requirements of the “Murkowski regulation”.
With the limits on Faecal Coliform, and Chlorine added into the preceding table the treated water meets the requirements proposed for waste water discharges in the Federal cruise ship legislation section 1404 (“Murkowski regulation”), and the Alaskan State legislation HB 260.
In addition to defining the standard of quality for the primary discharge of treated water any secondary discharges from the treatment system need to be identified, quantified and management / disposal strategies identified. These may include gas / vapour emissions, solid material / screenings with variable moisture content, and primarily liquid / slurry waste. The best option for dealing with each secondary waste will depend on the characteristics of the vessel that the treatment system is installed in. For instance, is there available incinerator capacity to deal with the volume of screenings, is there storage capacity to allow the holding of any generated slurry between discharge opportunities?
There may also be the possibility of using the treated wastewater to eliminate some other water treatment requirement, for instance use as compensating ballast that can be discharged to sea in port areas without the risk of introducing alien species.

4. Assessment and choice of appropriate technology

The wastewater contains a variety of contaminants, some being soluble and others being in a variety of solid forms, and which may be non-biodegradable, or with varying degrees and rates of biodegradability. In selecting a treatment process the ability to handle the complete range of contaminating materials needs to be carefully considered. This is not only from the aspect of generating a treated waste stream in conformance to the requirements, but also the amount and quality of secondary waste, and the reliability of the system when operating with the complete range of contaminants.

There are a wide variety of processes available, some developed to treat municipal or small community wastewater, and others designed to deal with industrial waste streams. Particulate matter may be separated out, using filtration or settling, possibly assisted by dosing with a flocculent agent. Settling can be by gravity, or assisted by a centrifuge or decanter. Chemical processes, using dosing or electrochemical oxidant sources, may be used to convert contaminating material into compounds that may be benign and/or more easily separated from the liquid phase. The most commonly used means of reducing the amount of organic contaminating material is to degrade by aerobic biological action, reducing organic material to principally water and carbon dioxide. In order to achieve the required standards of discharge water quality most practical systems use more than one technique to deal with the range of materials in the wastewater.

Almost all the possible treatment processes require a separation stage, to retain suspended solids within the treatment system. This is a critical choice, as it is likely to be the part of the process that regulates the process capacity. Particularly for the biological treatment processes membrane separation technology has been adopted, generally using low-pressure membranes. A full discussion of the merits of the alternative types of available low-pressure membranes for use with biological treatment systems would be somewhat lengthy. However it is worth noting the generic types of membrane available, and their applicability to the two principle methods of application:

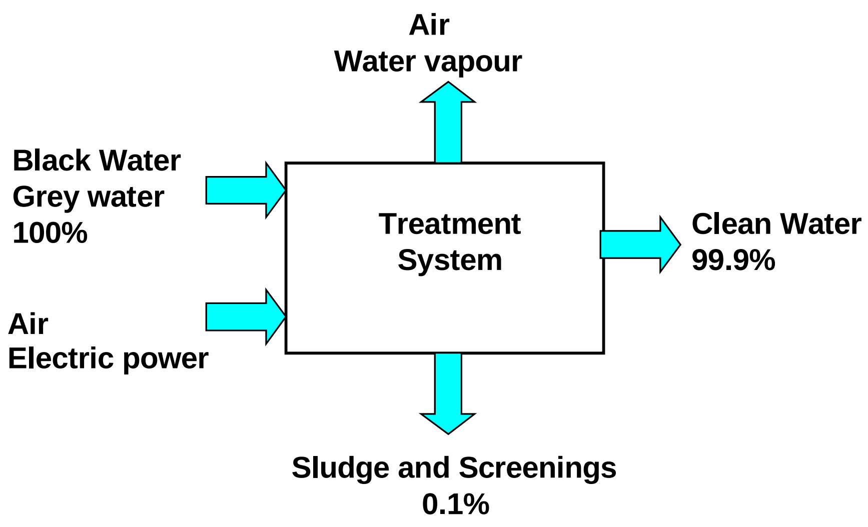
Membrane type	Method of application	Advantages
Flat sheet	Submerged in tank, air induced cross flow	Low membrane surface turbulence, membranes within dimensions of the treatment tank
	Sidestream in module casings, pumped cross flow	Good membrane surface turbulence, modules can be removed with system in service
Tubular	Submerged in tank, air induced cross flow	Fair membrane surface turbulence, membranes within dimensions of the treatment plant
	Sidestream in module casings, pumped cross flow	Excellent membrane surface turbulence, modules can be removed with system in service
Hollow fibre	Submerged in tank	Poor membrane surface turbulence, membranes within dimensions of the treatment tank

Submerging the membrane in the process tank has the benefit of minimising the volume of the system. However use of membranes in a side stream installation allows better control of surface fouling by turbulence in the cross flow, and allows either insitu cleaning or replacement of membrane modules with the system remaining operational.

5. Hamworthy design

The design team at Hamworthy KSE has a high degree of expertise in the design of biological digestion units for wastewater, particularly aerobic digesters. The development of a high rate biological digester, using a physical barrier including a suitable membrane for clarification, is a natural evolution of familiar technology. In addition the extensive experience of marine applications in the team has ensured that design options selected conform to the requirements of shipboard operation.
A bioreactor operating with a biomass suspended solids of around 20 g/l is capable of achieving very significant rates of organic material reduction, measured both as BOD_5 and COD. The rate of organic sludge growth is related to the ratio between the organic content of the incoming flow to the amount of active biomass in the bioreactor. The use of relatively high levels of biomass suspended solids ensures that this ratio is kept low, and the resulting rate of organic sludge growth is also very low.

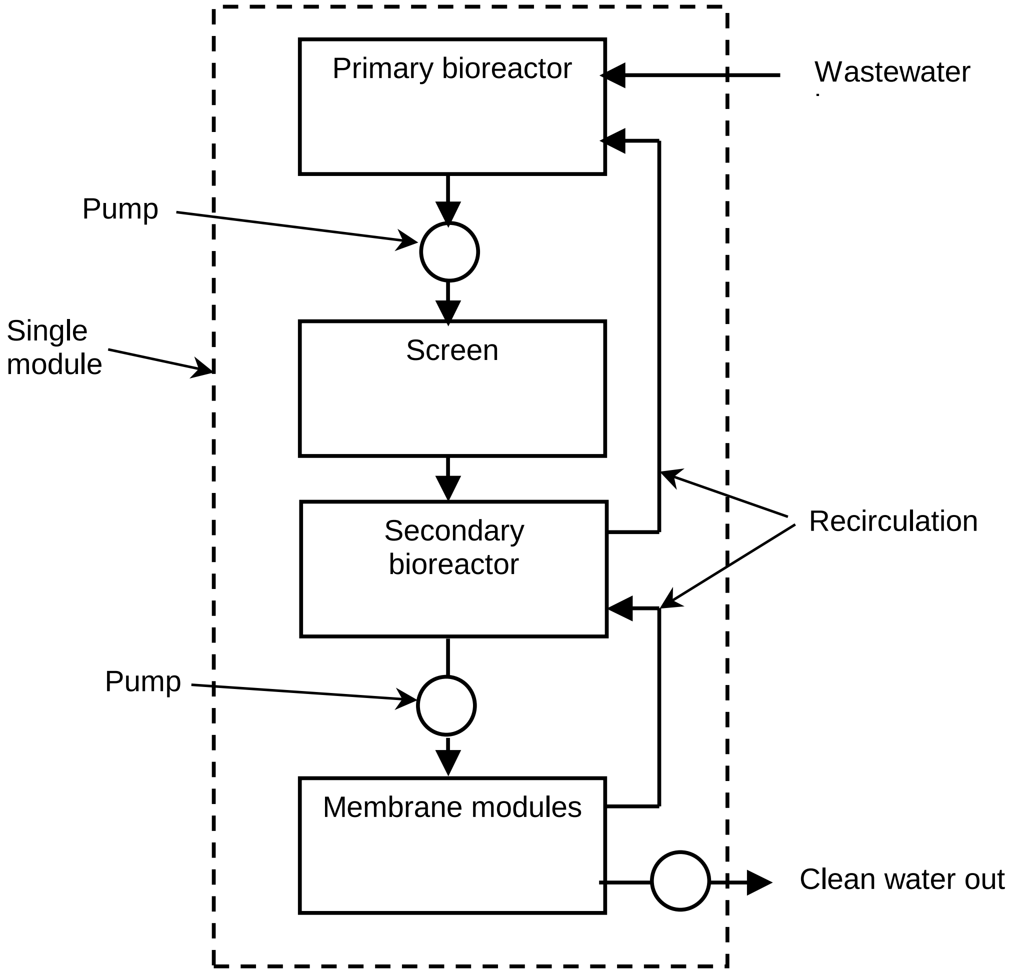
The incoming wastewater also contains non-biodegradable solids (or with very slow rates of degradation), typically plastics, grit, hair, fibres and some types of greases. These need to be removed from the system, by periodic desludging, or by extraction through a suitable screening system.



System Concept

Hamworthy have chosen to use tubular membranes, using 8 mm nominal bore tubes, mounted into 200 mm nominal diameter fibre reinforced casings. The membranes are rated in the ultra-filtration range, with a nominal pore size of 40 nano metres. These are used in side stream mode, with cross flow generated by centrifugal pumps.

Control of non-biodegradable material, or slow to degrade fibrous material, is by self cleaning filter, operating with an aperture size of 200 to 400 micron depending on the application. The system is arranged with a primary bioreactor, operating aerobically and reducing the incoming organic material by the action of the



Simplified system schematic

concentrated biomass, with a self cleaning filter in the transfer to a second stage reactor. The cross flow pumps draw from this second stage and pump through the membrane modules, returning a proportion of concentrated biomass to the primary bioreactor to maintain a balanced biomass.

6. Proving the system

Hamworthy KSE has operated a membrane bioreactor plant at our Poole site for about one year, arranged as a large-scale pilot plant treating about 30 tons per day of wastewater. The feed is municipal sewage, somewhat weaker in organic strength than vacuum collected sewage, but equivalent to the combined sewage and grey water mix on an average passenger vessel. Comparison with shipboard conditions has shown that significantly higher amounts of paper fibres are present in the ship's system than in the municipal sewage. Additional toilet paper has therefore been added to the trial plant feed obtain representative conditions. Results over 12 week monitored period have been:

	Average	Maximum single value
Suspended solids	7 mg/l	10 mg/l
BOD_5	5 mg/l	7 mg/l
COD	22 mg/l	30 mg/l
Coliform	3 counts / 100 ml	8 counts / 100 ml
Fats, oils, greases		Less than 10 mg/l

The pilot plant is being maintained in operation to test process and auxiliary system options to confirm performance under controlled conditions prior to shipboard use. It has been used to confirm start up procedures, which we have found to be relatively simple. We have also established data for low or zero feed periods, followed by immediate full load operation.

7. Shipboard installation

A nominal 60 ton per day membrane bioreactor has been installed on the Princess Cruises' vessel "Sun Princess", treating black and grey water. This was assembled into the ship over a six week period commencing 4 April 2001, and commenced operation from mid May 2001. Results of testing of the treated water discharged over a ten week period of operation commencing 28 May are:

	Average	Maximum single value
Suspended solids	18 mg/l	32 mg/l
BOD_5	12 mg/l	15 mg/l
COD	113 mg/l	117mg/l
Coliform	4 counts / 100 ml	7 counts / 100 ml

These results are well inside any current regulatory levels, including Alaskan State HB 260. Additionally the results are also inside the levels proposed in the US Federal Bill HR 5666 Section 1404 (the Murkowski proposals).
Completion of IMO and USCG certification testing is expected by the end of September.

During this initial period of operation we have noted a variety of conditions that the system has experienced, well outside those predicted.

- Temperature of the influent black water up to 70 degrees centigrade (design allowed for up to 55 degrees centigrade)
- Chlorine content of grey water above 5 mg/l for short periods, and at 1.5 mg/l for extended periods (design based on up to 0.5 mg/l)

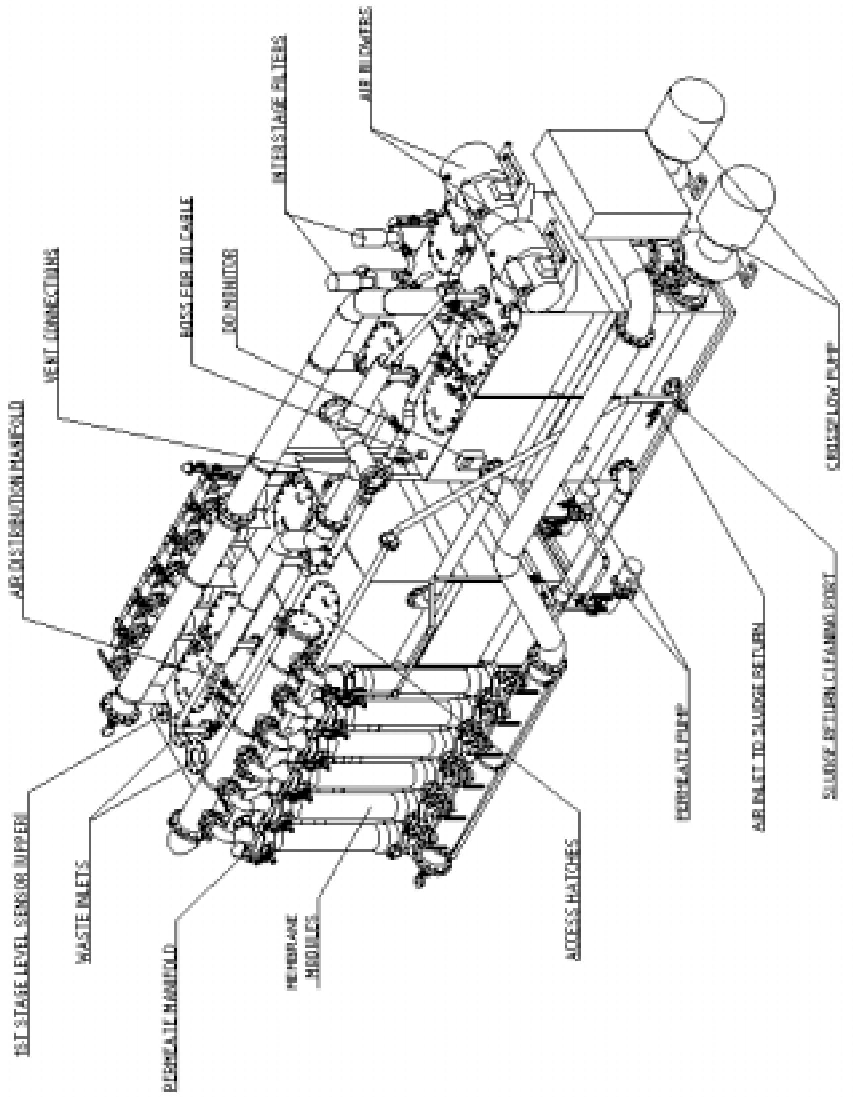
- Fats, oils and greases from galley waste water fed to the grey water collection system
- Cellulose fibres from paper in higher concentrations than predicted, with a pronounced tendency to stick together after initial breakdown

The system has handled these conditions well, giving good confidence in the robustness of the process.

8. Concluding remarks

The system developed has been shown to be capable of treating combined wastewater streams on generated on board ships to the highest effluent quality standards.

It is available as a complete modular package, minimising installation costs when used in new building or major ship conversion / upgrade projects.
It is also particularly well suited to installation into existing vessels by conversion of existing traditional biological treatment units using the extended aeration activated sludge process. Where these original systems were adequately sized for the effective treatment of black water only it is generally possible to convert to a membrane bioreactor capable of treating all black and grey water, with only a small amount of additional space being required for additional system elements.
Hamworthy KSE have recognised the special difficulties and challenges in meeting the diverse conversion project requirements. Suitable specialist project management, design and fieldwork teams have been set up to match the particular skills needs of the conversion, new build and upgrade requirements of the marine market.



Membrane bioreactor installed on MV Sun Princess