BLACK & GREY WATER TREATMENT SOLUTIONS USING MEMBRANE BIOREACTORS

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SUMMARY

The problems raised by increasing legislation defining the levels of wastewater discharge permitted give rise to an increased challenge both to ship operators and their equipment suppliers. The issue is more prevalent within the cruise industry where up to 1000m³ of wastewater can be generated per day.

This paper outlines the factors to be considered when designing an advanced treatment system onboard a cruise ship. Specific reference is made to the development of a combined high rate bioreactor and membrane separation system, capable of handling a range of wastewater streams and producing a high quality effluent, exceeding current and future legislation. Aspects of conversion of in-service cruise ships and operational experience are discussed.

AUTHOR'S BIOGRAPHIES

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Joined BP Tanker Company as an Engineer Cadet and following six years as an Engineer Officer with BP joined Hamworthy Pumps and Compressors as a sales estimator. Following three years working in the London office and various management positions was appointed Sales Director of Hamworthy Marine in 1992,a position that is currently held.

1. INTRODUCTION

The Hamworthy KSE Group has a multi-product capability, dedicated to the design, manufacture and supply of specialist equipment and services to the marine industry. Many of our product groups, not only hold positions of technical leadership in their respective market sectors, but also have strong historical sales and operational experience. This is particularly true in the case of the wastewater treatment systems, where over 6000 sewage treatment units and around 2000 bilgewater separators are in operation.

Due to the specialised demands of the marine industry, when designing or improving products, close co-operation must be maintained with the shipowners, shipbuilders and consultants to ensure that the equipment will meet not only the operational demands of the user, but the legislative requirements that are either in force or proposed. Due to the reduced manning of today's vessels, it is a pre-requisite to design equipment and systems specifically for ease of operation that provide a high degree of self-monitoring.

In considering the new technology [1] which is available for black and grey water treatment, it is important to assess the widest possible range of alternatives and provide the optimum solution for the industry.

Not surprisingly, the cruise industry has led the way in advanced waste system technologies. The treatment of wastewater has received major attention in the last few years. The professional approach adopted to the 'Alaskan' requirements for ships visiting the territory is a testament to this.

There are numerous factors to be considered in the evaluation process of a system. These are discussed in more detail.

2. KEY INDICATORS FOR CHANGE

The discharge of ship wastewater is regulated in Annex IV of the international IMO regulations (MARPOL 73/78). That annex [2] generally prohibits the discharge of defined wastewaters, except where such wastewaters have been treated in an officially approved treatment facility.

It is apparent that the current IMO/USCG standards for the overboard discharge of treated sewage (black water) are not sufficient to meet the requirements and expectations of those bodies responsible for regulating areas of outstanding natural beauty, or areas of scientific interest. In particular there is no legislation relating to the treatment of wastewater generated from laundries, galley's, showers or sinks etc., (grey water).

The limitations of the standards may be acceptable for ordinary commercial cargo vessels. However, any changes to the IMO standards can be particularly influential to cruise ship design and operation due to the waste stream loading from the 'Hotel Services' as illustrated in Section 4.

The demand for cruise ships to visit unique areas, such as Alaska, has heightened sensitivity and awareness to waste discharges. This has led to more stringent legislation for black water, and importantly, grey water is included for the first time. Details on the controlling and enforcing the quality of effluent being discharged are addressed. Penalties in the event of non-compliance, for example, can be costly, both in monetary terms and public perception of the cruise company. Whilst at present these new standards are limited to Alaska, we can expect similar action to be taken in other areas of the world, where concerns exist for the protection of the environment.

There is strong public pressure on Canadian authorities to introduce legislation; Hawaii is also studying the situation. In general, where a high concentration of Cruise vessels visit areas of special interest, we consider these areas as primary regions where legislation will be introduced.

The players within the cruise industry, owners/operators, yards and specialist equipment suppliers all have a role to play in managing the step-change in design and operational demands that will result. To this end the six-point framework [3] prepared by the Cruise industry clearly depicts their intent, as stated below:

(i) **DESIGN -** constructs and operates vessels, so as to minimise their impact on the environment;
(ii) **DEVELOP** - improved technologies to exceed current requirements for protection of the environment;
(iii) **IMPLEMENT -** a policy goal of zero discharge of MARPOL, Annex V solid waste products by use of more comprehensive waste minimisation procedures to significantly reduce shipboard generated waste;
(iv) **EXPAND** - waste reduction strategies to include reuse and recycling to the maximum extent possible so a to land ashore even smaller quantities of waste products;
(v) **IMPROVE** - processes and procedures for collection and transfer of hazardous waste; and
(vi) **STRENGTHEN** - programs for monitoring and auditing of onboard environmental practices and procedures in accordance with the International Safety Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM Code).

3. DETAILS OF THE CHANGES

It is worth noting that the provisions of the Annex (IV) were ratified very recently, nearly 20 years after the original filing. The main driver for the Alaska cruise ship emission regulations [4] can be traced to the lack of appropriate port facilities to receive and process ship waste and the high level of environmental awareness of the inhabitants whose livelihood depends on the health of the waters.

Effectively, the new standards place a responsibility on the cruise ship operator to develop pollution prevention and waste management solutions, including advanced technology and systems that minimise or ideally eliminate pollutants.

	Units	**Current**	**Current**	**Alaska**
		USCG 33CFR 159 PT1-300	IMO MARPOL 73/78 Annex IV	40CFR 133 33CFR 159 PT300-600
Test Duration	Days	10	10	30
Suspended Solids	mg/l	150	50 (100 at sea)	30
BOD_5	mg/l	Not required	50	30
Faecal coliform	Count/100 ml	200	250	20
pH		Not required	Not required	6.0 to 9.0
Chlorine	mg/l	Not required	As low as practicable	10.0

Included in the standards are rigorous testing regimes on a wide variety of performance measures. Including random, unannounced sampling by the enforcing agencies.

4. DEFINITION OF THE WASTE WATER CHALLENGE

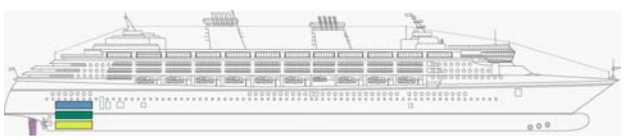
The enormity of the challenge faced by the cruise industry can only be appreciated by the relative comparison of typical wastewater volumes generated by three generic ship types as shown below:

LOA 274m, Disp 150,000 tonnes, Compliment 24

Suezmax Tanker

Destroyer

LOA 152m, Disp 8,000 tonnes, Compliment max 235



Passenger Cruise Vessel

LOA 288m, Disp 109,000 GT, Compliment 4400

DAILY HYDRAULIC LOAD m^3	
Suezmax	4
Naval Destroyer	54
Cruise Ship	960

A closer examination of the sources of the wastewater streams is as follows;

	CARGO VESSEL	MILITARY VESSEL	CRUISE VESSEL
Typical compliment	24	235	4,000
Black Water (vacuum) m³	0.6	2.4	100
Sanitary Grey Water m³	1.2	34	570
Laundry m³	0.5	8.2	130
Galley Water (excl. food waste & GDU) m³	2	9.4	160
TOTAL m³	**4.3**	**54**	**964**

Essentially, any design of treatment system requires comprehensive understanding of the sources and composition of wastewater. The strength of the waste, the amount of suspended solids and their degradation time, are some important parameters that must be considered in selecting the appropriate treatment process and potential improvements that need be implemented in current practices.

The wastewater contains a variety of contaminants, some are soluble others being in solid form. These may be non-bio-degradable, or with varying rates of biodegradability. Typical components of the various waste streams are;

Black	Acc Grey	Laundry	Galley	Gdu Pulpers
Paper	Plastic	Softeners	Grease	Acids
Plastics	Hair	Lint	Fat	Fat
Solid waste	Oils	Detergent	Food waste	Food waste
Cleaners	Cleaners			

Contaminants may severely influence the process efficiency and affect the reliability of the treatment system. One aspect to be recognised is that shipboard waste management is far more complicated than land-based.

5. CHOICE OF APPROPRIATE TECHNOLOGY

There is a wide variety of treatment processes available, some developed from land based applications, and others specifically designed for the marine environment. Particulate matter in the waste stream 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 can be used to convert contaminating material into compounds that may be benign and more easily separated from the liquid phase. 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.

General belief within the industry is that membrane bioreactors (MBR's) will form the basis of the waste technology. Extensively used in land-based applications, the challenge has been the adaption to the Marine environment. In the wake of Alaskan legislation, there is no doubt that compromises will have been made in the design as the vast majority of MBR's have been applied to the retrofit market, where severe constraints are placed on the system designer.

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	Comments
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

6. ADVANCED TREATMENT TECHNOLOGY

6.1 HAMWORTHY KSE – MBR DESIGN

The new Hamworthy KSE membrane bioreactor (MBR) is a development of the conventional Super Trident design by virtue of the fact that it is based on the digestion of organic waste by aerobic bacteria.

The limiting design parameter of the Super Trident is the design of the clarification stage. The use of a conical settling tank requires a stable sludge blanket to be formed to prevent carry over of the activated sludge into the final effluent. Any number of external influences can cause a variation in the formation of this sludge blanket resulting in varying effluent quality. The use of a membrane at the clarification stage provides a physical barrier that guarantees effluent quality.

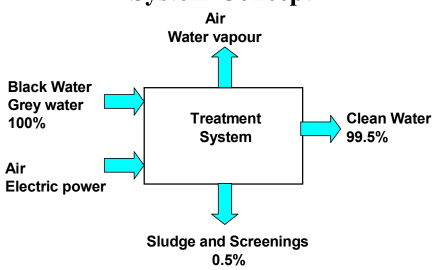
The membrane separation systems that were available upto 2 or 3 years ago were based on the membrane modules used for potable water production. These are relatively high differential pressure units that are contained in pressure vessels. Use of these systems with wastewater resulted in large, complex installations that suffered from rapid blockage, primarily due to bacterial growth both on and within the membrane material.

Continued development of membrane materials specifically for the treatment of wastewater streams has resulted in units that are able to operate at a much lower trans membrane pressures (TMP) and have good anti-fouling surface properties. These units can be exposed to activated sludges for extended periods and have allowed practical systems to be designed.

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.

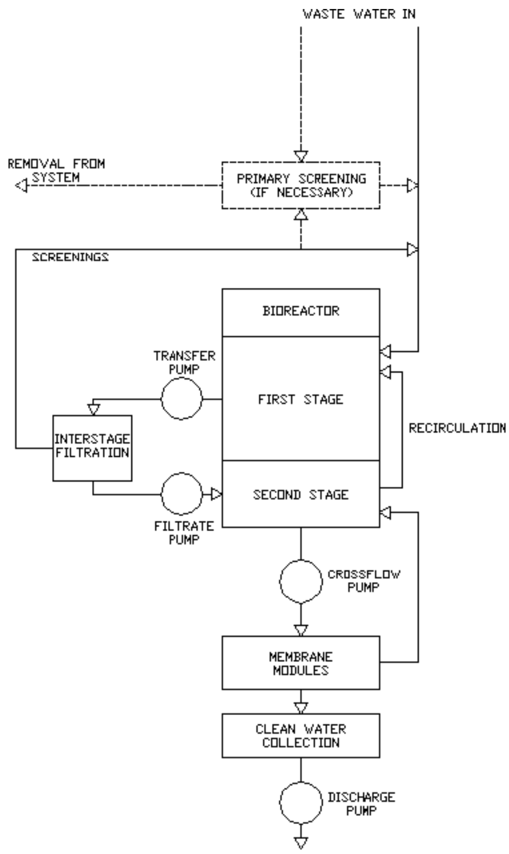
System Concept



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 a 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 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.

MBR Schematic Diagram



7. SHIPBOARD INSTALLATION

In any shipboard retrofit programme it is important to approach the challenge in a structured way. The chart below depicts a typical process flow.

VESSEL EXAMINATION

- Determine existing holding/ /treatment systems

OPERATIONAL PHILOSOPHY

- Hotel services - Daily routine, operating regimes and management cleaning chemicals
- Engine room – Daily routine, operating regimes and management
- Collection, holding and treatment capacities
- Knowledge base of ships staff

DISCUSS AND REVIEW FINDINGS

- Emphasis on waste minimisation
- Optimisation of operational practices

TECHNO-ECONOMIC SOLUTION

With the majority of current activity being on cruise vessels already in service, much work has been focussed on integrating into current operating conditions. These include:

- Legislation requirements current (and future)
- Existing Grey/Black water treatment facilities
- Shipboard storage capability
- Waste management philosophies – hotel services
- Shipboard operational philosophies – engine room
- Vessels cruise atlas.

Even current newbuild enquiries are generally option vessels or repeat designs, and therefore have constraints as the engine room layout is predominantly based on the 'traditional' treatment plants. Conversion of the "traditional" treatment plant into advanced wastewater treatment systems is possible. Hamworthy KSE have converted a number into 240 and 320 ton per day membrane bioreactors. First off units of each size have been subject to full shipboard IMO and USCG type approval trials, including independent test authority collection and analysis of 40 samples of feed and treated water over a ten day period.

Effluent quality results achieved were:

	Geometric mean
Total suspended solids	<2 mg/l
Organic content BOD_5	2 mg/l
Faecal Coliform	13 counts/100ml

It should be noted that the HKSE system does not use any disinfectants, i.e. chlorine addition, depending entirely on the performance of the bioreactor and membrane to eliminate bio-organisms from the effluent. Monitoring of faecal coliform is difficult in these circumstances, as minor contamination of test sample points can lead to individual samples with high faecal coliform counts. However these difficulties in accurate sampling need to be set against the benefit of zero disinfectants addition.

All results were well inside the criteria set by IMO and USCG, and full certification has been granted.

During the period of operation the units experienced conditions, which were beyond those originally predicted.

- High feed inlet temperatures - up to 70°C
- High feed concentration - up to 6500mg/l
- Chlorine content of grey water above 5mg/l
- Cellulose fibres concentrations higher

The system coped with these conditions.

The membrane bioreactor system lends itself easily to newbuildings, as the footprint taken up will be less than that for conventional black water treatment plants. It is also ideally suited to converting existing sewage treatment plants to comply with the legislative requirements.

8. CONCLUSION

It is generally acknowledged that the requirements relating to black and grey water treatment on cruise ships trading in Alaska, will in time extend to other areas of the world where high concentrations of cruise ships operate.

A majority of vessels will therefore undergo modifications to enable compliance and facilitate fleet-wide flexibility of operation. The industry pre-empted the market shift to more advanced technologies, however, the pace of change was not.

There are a large number of varying technologies available for the cruise operator to choose from resulting in a vast array of 'total waste' solutions on offer.

In the development of the waste management system, the optimisation of waste generation, system compliance to the regulations, and operational reliabilities are major factors to be considered. In principle, the optimum design should provide the owner with adequate flexibility such that the vessel is effectively 'self-sufficient' with respect to shore wastewater management facilities.

On retrofits this is almost impossible, hence any system installed must be robust enough to accept the varied operational demands including environmental laws, Port reception facilities, vessel itinerary and even passenger demographics.

Currently, no one individual company can claim to provide exclusively a total waste management solution. The specialist skills and experience necessary are shared globally within the industry.

There is clearly a need for a review of the considerable progress made to date with particular reference to the future and a case for the industry as a whole to share the knowledge base in an effort to find the optimum environmental solution.

9. ACKNOWLEDGEMENTS

Hamworthy KSE Group is a world-recognised company in marine equipment and systems technology. The Poole based company has been a major supplier of marine wastewater treatment systems for more than 35 years. Continuous product development, in particular, as directed by the cruise industry, combined with the availability of new technologies has led to significant advances in the standards of wastewater treatment that can now be achieved.

We wish to acknowledge, the co-operation of the management and staff of Princess Cruises plc and Celtic Pacific (UK) Ltd.

10. REFERENCES

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