THE ROYAL NAVY

MEETING THE ENVIRONMENTAL CHALLENGE FOR THE 21ST CENTURY

BY

LIEUTENANT COMMANDER D. STEPHENSON, BENG, MSC, RN
(*Warship Support Agency – MEAS3B*)

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ABSTRACT

Environmental compliance for military vessels with International and host nation regulation is more than just satisfying the requirements of legislation and avoiding negative press. Environmental compliance is a key factor in operational capability, which produces the following benefits:

- Enhanced mission endurance.
- Reduced operating costs.
- Increased port independence.
- Unrestricted operational freedom of passage.

Selection of suitable technologies to treat maritime waste streams can provide the above benefits following development to suit military application. This article sets out the Royal Navy's commitment to environmental compliance, through a programme of equipment development to meet current and future environmental regulation, describes those technologies identified to improve operational capability and outlines in brief a technology insertion programme to reap the above benefits.

Introduction

The Royal Navy embarked upon a technology development programme in 1997, to identify and develop existing and emerging technologies, for use in its surface and sub surface vessels that would improve operational capability and endurance. The MAES3b equipment section of the Marine Auxiliary Environmental and Steam Systems (MAES) Integrated Project Team (IPT) of the Warship Support Agency was tasked to identify technology in the MARPOL area. This programme has resulted in 3 different technologies being brought to maturity and equipment utilizing these technologies being installed in Royal Navy ships.

The programme sought primarily to improve the operational capability of vessels whilst paying proper regard to environmental considerations. Improvements in operating capability are measured in reduced maintenance, greater automation and extended mission endurance between waste off load. Other targets are value for money, improved reliability and compliance with environmental legislation.

The 3 technologies to be discussed in this article are:

- Membrane Bio Reactors.
- Ceramic Membrane Bilge Water Separators.
- Pyrolysis destruction of Sanitary Waste.

Other NATO nations have similar development programmes and much information is shared between member states in the working forum of NATO Special Working Group 12.

Background

The Navy Board's Environmental Policy Paper[1] and the Secretary of State for Defence's Environmental Policy Statement[2] clearly mandate compliance with existing International marine discharge standards and compliance with foreign host national standards where possible. Both documents also direct the MoD to consider emerging and future regulations, implementing technology assessment and equipment development programmes where necessary, to ensure that the Royal Navy maintains its legal right of passage in international waters and continues to enjoy access to many states national waters. Whilst MARPOL 73/78 allows exemption from the regulation for military vessels[3] the UK Government, as with many other Governments, specifically disallows crown immunity.

Royal Naval vessels are fitted with equipment to ensure compliance with current MARPOL 73/78 regulation, however, anticipated future changes to these regulations may render some of the 'as fitted' equipment obsolete and require alternative treatment processes for marine waste to be identified.

At the outset of the assessment and development programme it was essential to apply a credible set of discharge standards that would anticipate possible future tightening of existing regulations. Those selected came from a study conducted for the NATO Industrial Advisory Group (NIAG).[4] Aimed primarily at liquid discharges the standard was arrived at in consultation with European equipment manufactures as being technologically achievable by 2005. The NIAG standard stipulates a single set of criteria applicable to all liquid waste effluent streams which are more restrictive than the MARPOL 73/78 equivalent, these criteria are shown in Table 1.

TABLE 1 – *NIAG liquid discharge determinant standard*

EFFLUENT CONSTITUENT	MAX ALLOWABLE LEVEL
Biological Oxygen Demand (BOD_5)	30 mgl^{-1}
Chemical Oxygen Demand (COD)	300 mgl^{-1}
Chlorine	not permitted
Total Solids	500 mgl^{-1}
Total Suspended Solids	100 mgl^{-1}
Total Dissolved Solids	500 mgl^{-1}
Total Organic Carbon	100 mgl^{-1}
Oil and Grease	5 mgl^{-1}
Total Nitrogen	40 mgl^{-1}
Total Phosphorus	10 mgl^{-1}
pH	6-9
Faecal Coliforms	2 $CFUml^{-1}$
Foreign Organisms	2 $CFUml^{-1}$
Metal Salts	100 ppb for certain metals

Having adopted a standard the effect on operational capability, freedom of passage and endurance, was assessed against it to identify the areas where unacceptable or restrictive limitation would result. Those areas assessed as potentially limiting capability were the discharges of black, grey and bilge water effluent. The assessment of available technologies and equipment development to meet this standard is discussed further.

Membrane Bio Reactor (MBR)

The proposed NAIG criteria prohibit the untreated discharge of grey water, in addition to tightening the purity standard for black water effluent. In order to reduce assessment and development costs a single treatment process for both waste streams was sought. MBRs in use in large-scale land based municipal sewage treatment works meet the dual waste stream process performance criteria. This equipment uses established Commercial off the Shelf Technology and has good potential to be adapted for shipboard use. After conducting a market survey of membrane manufacturers[5] the KUBOTA cross flow membrane system was selected for use in a shipboard application. Selection was based upon a number of factors including

- Cost.
- Reliability.
- Performance.
- Product longevity.
- Ease of marinisation.
- Proven Operation.

To prove its ability to treat black water (Sewage) to the required standard a pilot plant[6] was constructed and operated for a period extending from July 1998 to February 1999. During this time the process efficiency was assessed using a number of different influent waste streams:

- Black water.
- Combined black and grey water (Domestic i.e. showers etc.).
- Grey water.
- Combined black, grey and oily water.

These trials established the ability of the process to deal effectively with a combined black and grey water influent.

In order to design and build a plant for use at sea, using the experience gained from the pilot study, it was agreed to build and test a full scale working technology demonstrator at a shore location. DERA, in conjunction with MBR Technology and Transvac Systems, were contracted to undertake this work at the DERA Haslar facility in Gosport, Hampshire, UK. To size the plant correctly and to ease later integration into a vessel the Royal Navy Type 23 frigate was selected as the candidate ship for future sea trials. A Type 23 frigate has a crew size of approximately 180 people and the class represents 45% of the Royal Navy's frigate and destroyer complement. In addition, this class already had the facility to collect domestic grey water internally, which lent itself well to integration with the proposed plant.

The current black water fit on a Type 23 frigate consists of 2 holding tanks each of 8 m^3 capacity situated in a common compartment connected to a vacuum sewage collection system. Black water is stored for up to 7 days after which it is either discharged to shore reception facilities when in port or discharged overboard in accordance with current regulation. Grey water is collected in 1 tank forward and in one of the black water tanks aft. Forward and aft grey water is discharged directly overboard when regulation allows or to shore reception facilities, the aft grey water when collected in the black water tank is treated as black water. Black water is generated at the rate of approximately 1.8 tonnes per day and grey water at a rate of between 30 and 35 tonnes.

The design specification for the black and grey water treatment plant stipulated a mission endurance of 45 days without the requirement to make a discharge of sludge, effluent quality meeting the NIAG 2005 discharge standards (Table I) and the need to make use of as much of the existing system equipment as possible to reduce installation costs.

Previous analytical work had been undertaken to estimate the volume of sludge production when using a vacuum black water collection system in conjunction with a gravity grey waste collection system.[7] The results from this study set the:

- Sizing requirement for sludge storage.
- Plant airflow throughput.
- Area of membrane surface required.

Combining the outcome of this study with the above design constraints confirmed that the plant was viable.

All of the constructive work at DERA Haslar was completed in a volume equal to that available on a Type 23 frigate with all new plant components sized to allow them to pass through a standard ship hatch size of 840 mm by 840 mm. Utilizing the existing 2 cylindrical stainless steel collection tanks for the membrane bio reactor process and sludge retention respectively, a 0.5m insert was welded longitudinally into both tanks to increase each tank working capacity to $9m^3$. A third tank, Mixed Liquor Balance Tank (MLBT), was constructed between the MBR and sludge tank to provide a surge flow buffer and mixing tank for black and grey water.

From the pilot study, and further analytical work, it was concluded that 200 KUBOTA half-size membrane panels were required to deal with anticipated 'in service' plant loading. An additional 10% extra capacity was built into the design to allow for growth resulting in four 55 vertical membrane panel stacks mounted in the MBR tank in the longitudinal direction. The additional 0.5m height of the MBR tank allows for the air diffuser pipe work to be installed internal to the tank and for the air to establish curtain flow before providing a scouring effect across the face of the membrane panels. The tanks are situated symmetrically approximately 0.5m either side of the keel thereby limiting the effect of ship motion on the liquid and diffuser air patterns within the tank. Coarse air bubble diffusion is initially used to aerate the tank, after 15 days a secondary fine air bubble system is activated to supply additional oxygen to the thickening bio mass.

Operation of the plant is similar to the pre-conversion system in that black water is collected under vacuum by the existing collection system, and is mixed with grey water from the aft grey water system in the MLBT before being pumped into the sludge tank. Liquid is pumped on level demand from the sludge tank to the MBR tank to maintain the tank level as clean permeate is discharged. Forward grey water is transferred aft to the MLBT by the control system as necessary to meet demand for process liquids.

During the land based trial black water collected from Type 23 frigates was used as influent for the black water stream and a simulated grey water mix, made up on site, for the grey water stream. Grey water was fed to the MLBT from a single tank for simplicity during testing. Both liquid streams were kept separate from one another and only mixed in the MLBT prior to treatment. A loading programme was established to mimic the variations in black and grey water production to represent a typical ship generation profile. This programme catered for expected peaks in flow rates throughout the day and for reduced manning periods such as weekends alongside.

In order to establish a viable bio mass prior to testing the plant was seeded with activated sludge at a density of $4000 mgl^{-1}$. It is a recommendation from this work that prior to use at sea the plant should be seeded with a similar density activated sludge to obviate the need to operate with reduced permeate flux whilst the bio mass establishes itself.

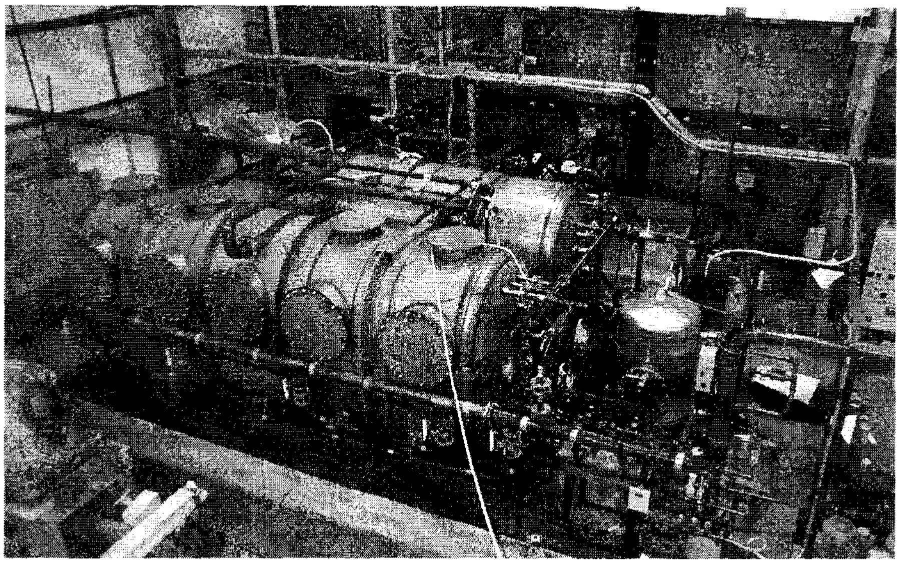

FIG.1 – AERIAL VIEW OF DERA T23 MBR PLANT SHOWING TANK ARRANGEMENT WITH MLBT SITUATED BETWEEN THE TWO LARGE CYLINDRICAL TANKS

After the plant had been commissioned a full 45 day trial period was commenced to replicate a typical mission of equal endurance with the loading of the plant replicating the ship generation profile.

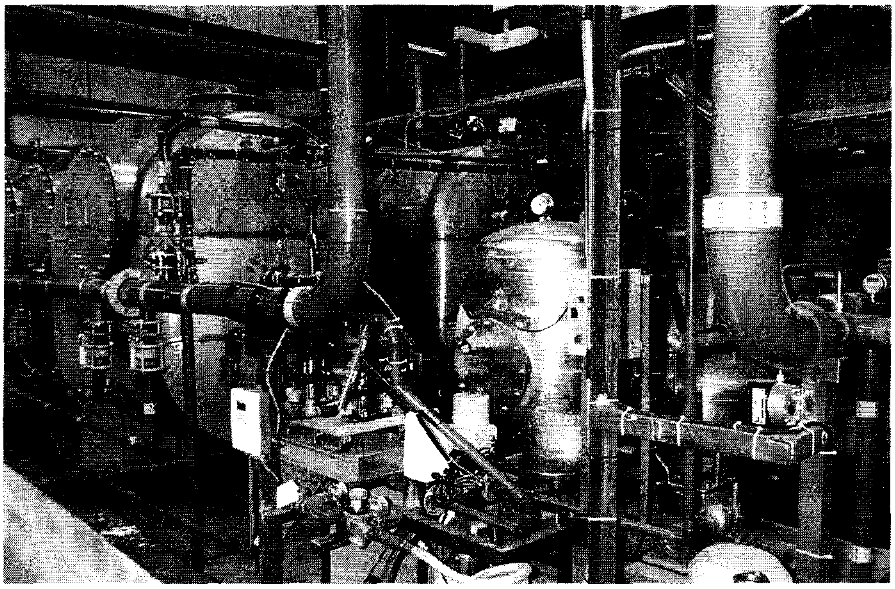

FIG.2 - FRONT VIEW OF DERA T23 MBR PLANT SHOWING VACUUM COLLECTION TANK (CENTRE), MBR TANK (PORT), SLUDGE TANK (STBD) AND DIFFUSER AIR PIPEWORK

Results of the effluent quality as measured against the NIAG discharge standard are presented in Table 2 and are discussed below.

TABLE .2 – *Comparison of MBR plant effluent quality with the NIAG standard*

EFFLUENT CONSTITUENT		AVERAGED PLANT RESULTS	MAX ALLOWABLE LEVEL
1	Biological Oxygen Demand (BOD_5)	4.6	30 mgl^{-1}
2	Chemical Oxygen Demand (COD)	97.6	300 mgl^{-1}
3	Chlorine	<0.01	not permitted
4	Total Solids	670	500 mgl^{-1}
5	Total Suspended Solids	8	100 mgl^{-1}
6	Total Dissolved Solids	650	500 mgl^{-1}
7	Total Organic Carbon	19.3	100 mgl^{-1}
8	Oil and Grease	2.5	5 mgl^{-1}
9	Total Nitrogen	17.1	40 mgl^{-1}
10	Total Phosphorus	6.2	10 mgl^{-1}
11	pH	7	6-9
12	Faecal Coliforms	0.3	2 $CFUml^{-1}$
13	Total Coliforms	0.3	2 $CFUml^{-1}$
14	Metal Salts	80.9	100 ppb for certain metals

1. Biological Oxygen Demand (BOD).

   The system consistently produced a BOD level well below the 30 mgl^{-1} stipulated by the NIAG standard with little variation throughout the trial.

2. Chemical Oxygen Demand (COD).

   The system consistently produced a COD level well below the 300 mgl^{-1} stipulated by the NIAG standard, though small variations were seen in this parameter.

3. Total Chlorine.

   The NIAG standard stipulates a chlorine free discharge. Chlorine was measured in small amounts in the effluent discharge throughout the trial but with a trial average of less than 0.01 mgl^{-1} the amount is though to be negligible and acceptable for marine discharge. All water generated on Royal Naval vessels is chlorinated as a matter of course to ensure potablity therefore its presence did not give undue concern.

4. Total solids.

   The plant effluent quality did not meet the required 500 mgl^{-1} standard in this instance primarily because of the high levels of total dissolved solids in the effluent. The reason for this is discussed below under point 6.

5. Suspended solids.

   The system consistently produced a suspended solids level well below the 100 mgl^{-1} stipulated by the NIAG standard with little variation throughout the trial.

6. Total dissolved solids.

   The plant did not achieve the stipulated level of 500 mgl^{-1} in this instance. This is due to the high concentration of chloride salts found in vacuum collected sewage. However, since the target parameter was set equal to the total dissolved solid limitation for drinking water an average level of 650 mgl^{-1} is though to be acceptable for marine discharge. A simple activated carbon post treatment effluent filtration would reduce this level significantly.

7. Total organic carbon.

   The system consistently produced a total organic carbon level well below the 100 mgl^{-1} stipulated by the NIAG standard with little variation throughout the trial.

8. Oil and grease.

   The system consistently produced an oil and grease level below the 5 mgl^{-1} stipulated by the NIAG standard with little variation throughout the trial.

9. Total organic and ammoniacal nitrogen.

   The system consistently produced a total organic and ammoniacal nitrogen level well below the 40 mgl^{-1} stipulated by the NIAG standard with little variation throughout the trial.

10. Total Phosphorus

    The system consistently produced a total phosphorus level well below the 10 mgl^{-1} stipulated by the NIAG standard with little variation throughout the trial.

11. pH

    The pH value of the permeate remained within the 6 – 9 band stipulated by the NIAG criteria.

12. Faecal Coliforms

    The system consistently produced a faecal coliform level well below the 2 $CFUml^{-1}$ stipulated by the NIAG standard. For a significant period coliforms were not detected in the effluent.

13. Total Coliforms

    The measured total remained below the NIAG criteria.

14. Combined Metals

    The following metals were present in the effluent from the plant, at levels that when summed, remained below the NIAG limit of 100 μgl^{-1}: Chromium, Copper, Lead, Nickel, Zinc, Aluminium and Mercury.

In total the plant was run for 82 days including commissioning, the operational aspect of this figure equates to some 55 days of running with a combined black and grey water influent equal to that generated by a Type 23 frigate. At the end of this period the mixed liquor suspended solid density had not risen to the anticipated maximum 25 000 mgl^{-1} predicted by the pre trial analytical study. At this point the plant was shut down, however, the plant was continuing to meet the stipulated discharge criteria and did not require to be pumped down. The data gathered during the trial period demonstrates the ability of the plant to perform to the required standard and for the required duration.

The shore demonstrator plant remains at DERA where further work continues in assessing the effects of food wastes, oil wastes and biological cleaners on the plant process and membrane materials. It is intended to fit a similar system to HMS *Grafton* in September 2001, during a routine docking period, for further trials and optimization at sea. Should these trials be successful then consideration will be given to retrofitting all Type 23 frigates. With further modification a similar plant could be fitted to all Royal Navy ships fitted with a vacuum collect sewage system. An initial investigation to assess the plant suitability for use in submarines shows that further work will be necessary to identify the platform integration issues.

Ceramic Membrane Bilge Water Separator

The second area identified as possibly limiting capability and hence requiring an assessment and development programme was that of bilge water separation. Current generation IMO approved oily water separators have difficulty coping with the mixture of compounds routinely present in the bilges of military vessels, particularly surfactants. In order to comply with existing and anticipated future (NIAG) discharge requirements for bilge water, an alternative technology was sought. Several existing equipment were considered and membrane separation chosen as the technology for the programme.

Alan Cobham Engineering Limited won a competitive tender to build a prototype unit using membrane technology. They have extensive experience in the field of filtration, in particular the use of ceramic membranes, and brought this expertise to the development programme.

The design criteria for the unit was specified as being able to process bilge water producing a permeate quality better than 5 ppm at a permeate flow rate of 3 tonnes per day. The space envelope for the unit was sized at 1m by 1.5m by 2m. Only electrical power and fresh water are supplied from ship services.

Bilge water is pumped direct from the sullage tank to the unit which processes the liquid to remove the water as a clean permeate which is then discharged overboard via an oil content monitor alarm device. The process consists of a pre treatment settlement stage for the removal of free oil, which is extracted and then pumped to the contaminated oil tank, followed by the removal of water from the process liquid by the ceramic membrane. Retentate is recirculated around the membrane loop ensuring that all the free oil is captured. Automatic back flushing of the membranes occurs routinely during operation thus ensuring the membrane pores do not clog and helping to prolong membrane life. The periodicity of the back flush process can be manually adjusted to satisfy specific treatment conditions. A clean in place system allows in situ chemical cleaning of the membranes to take place as part of the routine maintenance procedures, cleaning periodicity is dependant upon influent quality and hours run but is anticipated to be only necessary after 3 standard 45 day missions. The membranes have been shock tested to 30g whilst retained in the membrane unit and used membranes may be heat treated to recondition the membrane to 95% of its original flux capacity. Further testing is necessary to determine how many times the membrane may be reworked in this way before performance is unacceptable.

Prior to independent testing at DERA Haslar the prototype unit underwent a continuous 45 day endurance trial. A simulated bilge water mix comprising of the compounds listed in Table.3 was injected into a simulated salt water feed in the ratio of 1: 19.

TABLE.3 – *Ceramic Membrane Bilge Water Separator – Simulated Bilge Water mix*

OIL	PERCENTAGE BY VOLUME
OM 100	15.6
OM 33	15.6
OX 40	15.6
OMD 113	15.6
F76	15.6
PX 24	2
OX 38	2
OX 95	2
OM 70	2
OX 164	2
PX 4	2
OX 72	2
OEP 220	2
OM 24	2
White Spirit	2
Quick break bilge Cleaner	2

During this 45 day period some 1,030 hours of treatment process time was amassed, greatly exceeding the anticipated running time during an equivalent period at sea. This equates to an availability figure of better than 95%. Other than the routine back flushing, conducted as part of the treatment process, the membranes did not require chemical cleaning.

The mean free oil content of the permeate measured over the 45 day trial remained below 4 ppm, with no excursions above 5 ppm, thus meeting the 5 ppm specification. It is believed that polishing of the permeate, if necessary to meet yet tighter effluent limits, will be possible by the addition of a simple activated carbon filter with an anticipated further improvement of permeate quality.

Some independent testing of the unit has been conducted at DERA Haslar, the testing was halted due to engineering reliability, not process, problems. These minor shortcomings are being addressed at the factory and the unit was returned to DERA Haslar for further testing during August 2001. The testing regime at DERA will include validation of the factory testing and a further 45 day endurance trial utilizing ship collected bilge water. However, data taken from the first trials period at DERA Haslar supported the findings of the factory testing. It is concluded that the unit will meet the 45 day mission endurance, even if run continuously, meeting the specified 5ppm or less permeate quality specification. Testing at DERA is scheduled to stop by October 2001 and data from this testing will be compared against that taken during factory testing to validate earlier results.

On completion of DERA testing it is intended to install the unit in a Type 23 frigate for a 6 month period of evaluation at sea after which engineering alterations will be made prior to production. The nature of the process lends itself very easily to increase permeate throughput therefore the capacity of the unit may be increased by making minor process adjustments. Similarly, reducing the size of the unit is equally straightforward. The modular configuration of the process will allow the unit to be modified for applications where space limitations require an alternative approach to equipment layout, thus making it suitable for retrofit applications. A commercial variant is being developed by Alan Cobhams and is expected to be available in 2002.

This equipment provides a reliable onboard treatment process for bilge water allowing the 45 day mission target to be met without the need to off load sullage thus aiding port independence and hence operational capability. The need to regularly make sullage discharges to shore reception facilities is reduced and operating cost savings are generated. A simple cost analysis shows that this unit may pay for itself in 6 months when operating in the wider Caribbean and American seaboard areas.

Sanitary Waste Machine

An area of work not particularly identified by the NIAG report but recognized by the Royal Navy as requiring further investigation was that of sanitary waste disposal. Approximately one third of all Royal Navy warships have Wrens serving in them ranging from compliments of 2 to 112. The Royal Navy currently operates a 'collection for disposal' contract with Rentokil Ltd for sanitary waste destruction. The waste is stored in bins in which sanitary waste is rendered chemically inert by a mix of compounds. The bins are removed for disposal ashore when the ship is alongside.

Ships operational profiles do not always allow regular and timely off load of collected sanitary waste nor does the contract offer a full world-wide coverage for commercial reasons. An onboard disposal technique is necessary to alleviate the problems with prolonged storage and the costs associated with disposal not undertaken via the Rentokil contract.

The design specification stipulated a unit no larger than 0.5m by 0.4m by 0.25m, weight less than 25 kg, power consumption less than 4Kw, volume reduction of at least 85% and a volume throughput of sanitary waste not less than $0.1m^3$ per week. Off gases and waste residues have to be suitable for discharge without further treatment.

Strachan and Henshaw Ltd, in conjunction with Morgan Automation Ltd won a competitive tender to produce a stand- alone disposal unit utilizing pyrolysis as the destruction technology. Pyrolysis was selected owing to its mechanical simplicity, low power requirement, minimized process by products and process residues suitable for disposal in existing black water treatment plants.

FIG.3 – FRONT VIEW OF SANITARY WASTE DISPOSAL MACHINE SHOWING THE TWO SEPARATE CHAMBER LIDS

The prototype unit comprises two independent treatment chambers each capable of processing 3 sanitary towels plus 3 tampons plus all associated packaging and applicator material or 15 tampons with all associated packaging and applicator material. Each chamber operates on a 3 stage cycle:

- Heating phase in which sanitary waste is rapidly heated in a reduced oxygen environment to char the waste product.
- Burn phase where air is introduced into the chamber to ignite uncombusted material.
- Flush/cooling phase where the small amounts of ash residue are sluiced out of the chamber.

Total cycle time is approximately 35 minutes after which the chamber is ready to be filled again with more waste. The temperature during the heating phase is held at 600° C and during the combustion phase can reach 700° C.

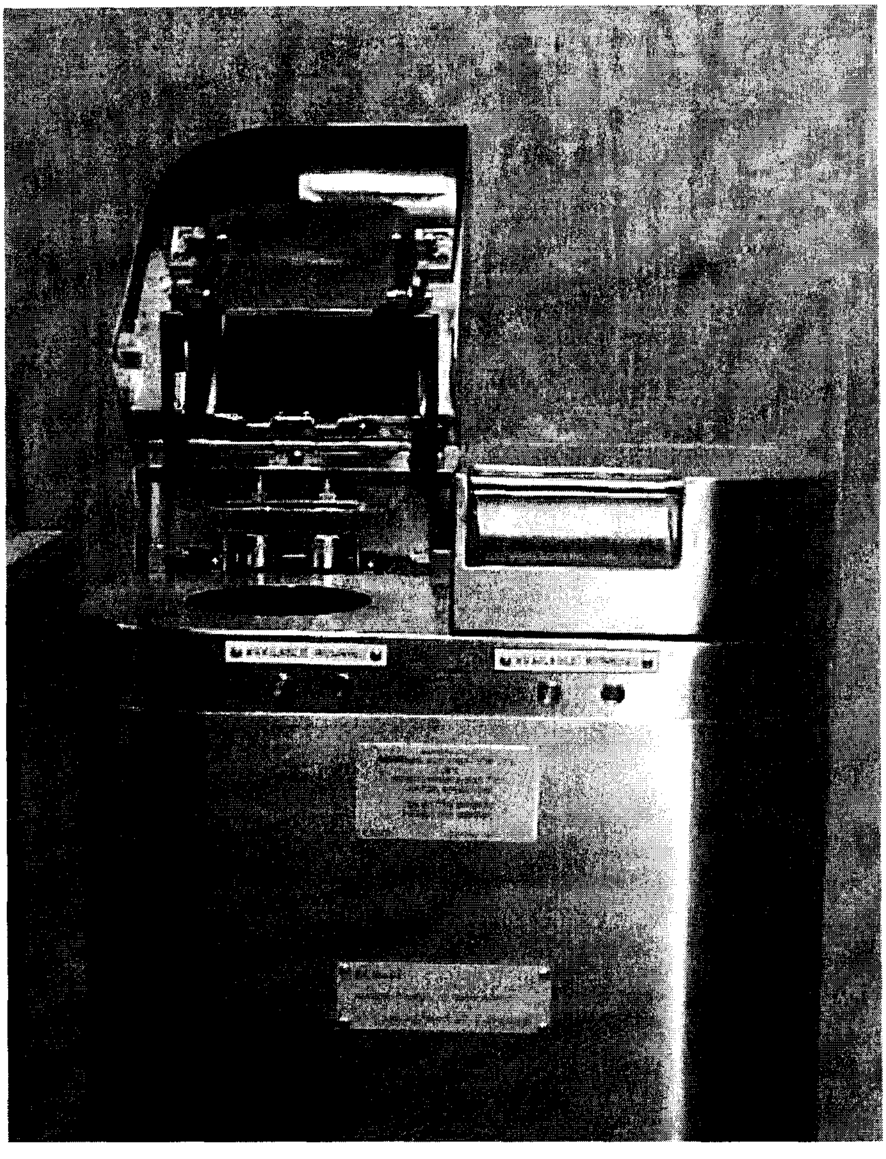

FIG.4 – FRONT VIEW OF SANITARY WASTE DISPOSAL MACHINE WITH LID OPEN EXPOSING CHAMBER 1

In order to ensure that the unit is not overloaded the control system counts the number of lid operations and automatically initiates a treatment cycle after 3 operations, this parameter is adjustable to suit particular ship conditions. To ensure that unprocessed waste does not accumulate for long periods the control unit monitors lid operation and lapsed time against a manually adjustable value, automatically initiating a treatment process when necessary.

The gaseous products of the treatment process are vented either to atmosphere or to the black water main and the ash residue is flushed into the black water main. Analysis of the off gases shows them to be suitable for untreated venting and the ash residue safe for disposal in a conventional sewage treatment plant.

The prototype unit has undergone factory testing with a range of commonly available sanitary products and has been assessed at DERA Haslar for operability. A more demanding process test regime at DERA is planned for November 2001 following necessary engineering modifications identified during previous DERA evaluation. This test regime will utilize biologically, chemically and blood contaminated products and will include an assessment of the unit's capability to cope with overloading.

It is intended to conduct a period of evaluation at sea toward the end of the year – it is anticipated that results from this evaluation will be included in the presentation.

Removing the need to store and off load collection bins will improve port independence, generate operating cost savings and remove the requirement to handle used storage bins.

Conclusions

The three equipment development programmes described demonstrate how the Royal Navy is meeting the requirement for capability enhancement through technology insertion in the MARPOL area. In each case operational endurance is increased by treating the respective waste streams more effectively than current generation equipment. Greater operational freedom is allowed owing to increased port independence via less reliance on shore reception facilities and operating cost savings are generated by a reduction in waste off load requirements.

Each equipment meets current (MARPOL) and anticipated (NIAG) discharge criteria providing the opportunity to ensure that Royal Navy vessels continue to enjoy unhampered right of passage in International waters and that they will continue to be welcomed in host State national waters.

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