Detailed Design of the Thermal Treatment System with Computer Simulation and Demonstration of the System

Executive Summary

Introduction

The use of ballast water as a vector for translocation of marine species has led to the need for an onboard treatment system, which can kill these organisms cheaply and with the least impact on the environment. The objective of this report is to present the state of the art high temperature thermal treatment system, to compare it to the existing low temperature thermal treatment systems and to present the steps undertaken in the design process of the high temperature system.

The effects of temperature on zooplankton and phytoplankton are presented, followed by the laboratory scale design and testing and the full size design. The report finishes with a look at corrosion problems and operational considerations.

High Temperature Thermal Treatment Laboratory tests

The laboratory tests were run over a period of two weeks in the beginning of June 2002, to ensure that these tests would represent the real world conditions experienced by the ballast water system; deionised water was mixed with the required salts in the right proportions to form “pure” seawater. Three different types of zooplankton and two types of phytoplankton were added to the water, these species were chosen as they were considered to be some of the most resilient species available and the most widely encountered in ballast water.
The laboratory scale treatment system evolved from a simple single heater, single cooler system, following preliminary testing, when it was found that the system would not give us enough control of the temperature and that high temperatures would not be possible. The system which was used in the experiments contained a pre-heater as well as the heater and cooler. The heat exchangers used glass coils immersed in insulated baths. The pre heater used an 11-spire coil and the heater a 22-spire coil, with ports to allow the use of thermocouples for temperature measurement. The insulated baths where heated using re-circulating heaters, 2 for the pre-heater and 1 for the heater. The soup was circulated through the system by gravity (using a header tank) to avoid the use of a pump, which would have a detrimental effect on the plankton and would interfere with the test, and was adjusted using a needle-valve flowmeter.
Three repetitions of the same test were used to eliminate any errors and the soup was treated at temperatures going from 35 to 65°C in 5°C steps.

Laboratory Test Results

Zooplankton

Following each test run the zooplankton was filtered out and stained with a special dye, which only reacts to ATP, live plankton would therefore be stained red, and the proportions of live and dead animals could be determined. As the phytoplankton was much smaller than the filter used, a 10-litre sample was collected post-filtering, for the Chlorophyll and Phaeophytin values to be determined. The results for the biological effectiveness of the treatment against the phytoplankton were obtained at the end of august. These show that the treatment is effective from around 50°C upwards, with a 100% killrate.

Phytoplankton

All the temperatures that were used by UNEW resulted in a reduction of chlorophyll a. However, experiments carried out at lower temperatures (40 and 45oC) resulted in a significantly lower reduction of chlorophyll a. It would therefore appear that temperatures of 50oC and above were more effective at reducing phytoplankton biomass. However, it would also appear that there is no significant effect between the results for treatments at 55, 60 and 65oC “Touch and Go”, which would seem to indicate that increasing the temperature above 55oC does not result in a corresponding reduction of chlorophyll a.

There is no clear indication from these results as to whether the “Touch and Go” method or the longer exposure method was more efficient. From these results it would appear that an increased exposure time at 55oC to 30 seconds led to a less effective reduction in the chlorophyll a level than the same experiment run at shorter exposure times. However, without the same experiment being repeated at different temperatures it is difficult to conclude whether this would always be the case or whether there were some other variables influencing the result. The experiments at 55oC were run using two different cultures, which may have had an effect on the results.

There were some different effects between the two phytoplankton species used, the Alexandruim sp. was reduced in 22 out of the 24 tests whereas there was a reduction in Thalassiosira sp. cell numbers in 18 of the 24 tests. The results for Thalassiosira sp. were more variable and showed reductions and increases when subjected to the same treatment. However, the overall finding was that there was no significant difference for either species in the mean change between the eight treatment methods. This indicates that there is a requirement for further investigation as to whether the cells are surviving the treatment or whether the cell counts are picking up cells that look normal but are actually dead. The results from the chlorophyll a indicate that there may have been a reduction in the number of cells that were alive.

Assessment of the environmental and corrosion risks caused by the treatment system

The treatment system on board ship will comprise two Alfa Laval heat exchangers, one pre-heater/recuperator and one treatment heater. The pre-heater will be heated by the treatment heater outlet water and will therefore reduce the temperature of the water been discharged overboard, limiting any environmental damage.
All the heating will be done in the system, using the titanium heat exchangers and there are therefore no increased corrosion risks to the ballast system or vessel.

System Simulation and Design

Static Simulation

Using Microsoft Excel a simulation program was designed which could give the required heat exchanger areas for given treatment and ballast water temperatures and de-ballasting and steam flowrates. This was done from first principles and therefore didn’t reflect what was achievable in on board ship.
To remedy to this a database of heat exchangers (both pre- and treatment exchangers) was created using CAS 2000, the program used by Alfa Laval to design its heat exchangers. This was then modelled using neural networks and inserted into a Labview virtual instrument (VI), giving us a static model.

Dynamic Simulation

The dynamic model was based on the same VI but took into account the dynamics and interactions of the pre-heater/heater system. This model allows us to vary all the parameters for the system: pre-heater and heater areas, the ballast water and steam inlet temperatures and the steam and de-ballasting flowrates, to give us the treatment and overboard temperatures, the energy used and the capital and running costs of the system.
This simulation program allows us to select the required pre-heater and treatment heaters to obtain the required treatment temperature for a given ship and sea route. It also allows us to choose the areas to minimise capital expenditure, running costs or to balance both costs.

Conclusions

With the problem of non-indigenous species being transported by ballast water gaining more attention and the problems associated to mid-ocean ballast water exchange, different ballast water treatment systems have been investigated by various parties. Thermal treatment has been a very promising solution, with the onboard trials of the low temperature treatment systems giving good results, but being limited by the long duration required achieve the temperature and the incapacitation of the organisms. This is a problem for short voyages and for partial de-ballasting and re-ballasting when the nutrient rich treated water is mixed with new seawater.

To combat these problems, high temperature treatment at exit must be used. By using high temperatures, the organisms are killed with a much shorter duration, which allows for shorter voyages and treatment at exit. Treatment at exit allows us to treat only the water which is being discharged, which eliminates cross contamination and any increased corrosion problems in the ballast tanks.
The effects of temperature on phytoplankton and zooplankton have successfully been tested under laboratory conditions. This has allowed us to obtain a correlation between kill-rate and temperature for *Acartia*, *Nereis*, *Tisbe*, *Alexandrium* and *Thallasiosira*, five of the plankton species most commonly found in ballast water. From these tests we have been able to deduce a treatment temperature for the high temperature thermal treatment system of between 55 to 60°C.

Finally from the design program presented in this paper, the heat exchangers required by the system will be sized and chosen. This will be done once the particulars of the ships and their routes on are obtained. With the proper design practices, there should be no extra corrosion problems, and the only remaining task would be to decide whether a fully automated control system would be used or if manual control is adequate.