Ultraviolet light, Ultrasound and Ozone methods, laboratory scale test trials

Executive Summary

The main objectives for the laboratory scale test trials in Work Package 3 were to design and development of the proposed methods and demonstrate their effectiveness against the selected organisms. Ultraviolet light, ultrasound and ozone methods were tested in two test phases. The preliminary test phase was carried out in Espoo, Finland, in April-May 2002. The aim of the preliminary test trials was to establish the operational parameters to the Newcastle test trials and study the effectiveness of the methods against *Artemia salina* and algae. The second test phase took place in Newcastle, UK, in June 2002, as part of the collective test trials.

The ultraviolet light device and ultrasonic devices were built in the same test rig in order to test single technologies and also to test the combination of ultrasound and ultraviolet light as part of hurdle technologies. The ozone device was a stand-alone device. The test arrangements included flow and pressure meters and required sampling taps before and after treatment process.

In Espoo trials *Artemia salina* and algae was used as the target organisms. Artificial sea water with salinity of 30-35 ppt and average temperature of 18 °C was used. Centrifugal pump was utilised when the water was introduced to the treatment process. Achieved total reduction of *Artemia* was 43-60 % with ozone treatment. The highest reduction rate was achieved on the slowest flow rate and on maximum ozone dosage (150 l/h, ozone dosage of 5.0 g/h). The contact times were short enough to affect only on activity rates but not on mortality rates of *Artemia*. Mortality rates increased rapidly with increasing contact time. With ultrasound treatment total reduction rates of 84-100 % were achieved, best result with flow rate of 200 l/h and with 50 % of maximum transducer amplitude. Regarding ultraviolet treatment, maximum reduction rate of 78 % was achieved with flow rate of 200 l/h and with ultraviolet dose of 562.5 mJ/cm^2.

Also the combination of ultrasound and ultraviolet light was tested as a part of hurdle technology. The result of total reduction of *Artemia* was 82-99 %, best results achieved with flow rate of 400 l/h and with maximum ultrasound amplitude and ultraviolet dose of 281.25 mJ/cm^2. Each test run was carried out only once, hence the results should be regarded as indicative. The algae culture used in the test trials was corrupted, thus the results were abandoned.

The test trials in Newcastle were carried out in early June 2002 in the facilities provided by Newcastle University. The test arrangements were the same than in Espoo trials, excluding the composition of the artificial sea water and the utilisation of the centrifugal pump. Standard seawater was prepared for all tests using de-ionised water added with Tropic Marine salt and the target organisms, i.e. *Nereis virens, Acartia tonsa, Tisbe battagliai, Alexandrium tamarense* and *Thalassiosira pseudonana*. During the first three and a half days centrifugal pump was used but after realising that the pump itself was eliminating all the zooplankton, a gravity system to supply the water was used. The mortality attained by the ultrasound treatment was always below 40 % for all the tests. The ultraviolet method did not inactivate more than 56 % of the zooplankton. The highest value for the ozone treatment was 89 %, eliminating *Nereis*. In terms of hurdle technology, a better performance from the Filter (125 microns) + ultrasound + ultraviolet test compared to the ultrasound + ultraviolet seems apparent, mainly for *Acartia* and *Tisbe*. As an overall observation, excluding the use of the filter, *Acartia* was the most resistant of the three species and *Nereis* the least.

Phytoplankton results showed that ozone were the most effective at reducing chlorophyll *a* levels with reduction rate of 97 % (flow rate 200 l/h, ozone dosage of 5,0 g/h). Ultrasound achieved the highest reduction rate of pheophytin level, 67 %, with flow rate of 400 l/h and amplitude of 50 % with after flushing sample. The highest reduction rate with chlorophyll *a* levels, 71 %, with ultrasound were also achieved with flow rate of 400 l/h and with amplitude of 100 %. With ultraviolet light treatment, the highest reduction rate of chlorophyll *a* level, 56 %, was achieved with flow rate of 300 l/h and with ultraviolet dose of 375 mJ/cm^2. The highest reduction rate of pheophytin level, 33 %, was achieved with flow rate of 900 l/h and with ultraviolet dose of 125 mJ/cm^2, in after flushing sample. The hurdle technology, ultrasound combined with ultrasound, achieved reduction rate of 68 % with chlorophyll *a* levels and 46 % reduction of pheophytin level (flow rate 300 l/h, US amplitude 100 %, UV dose 375 mJ/cm^2). The combination of filter (125 microns), ultrasound and ultraviolet light achieved the reduction rate of 57 % of chlorophyll *a* level and 52 % reduction rate of pheophytin level (flow rate 300 l/h, US amplitude 100 %, UV dose 375 mJ/cm^2) at its best.

In addition to the biological effectiveness of the methods, also possibly modification of the ballast water properties and contents by the treatment method was identified. Ultraviolet light causes a slight increase of the Redox potential (short term effect) with possible consequences on metal corrosion, coatings and gaskets. Regarding the ultrasound method no risk of corrosion increase or risk with respect to coating and gaskets was identified. Ozone method causes a significant increase of the Redox potential (short term effect) with possible consequences on metal corrosion, coatings and gaskets. Also the production of O_3 (short term effect) with possible consequences on metal corrosion, coatings and gaskets was identified.

Along with the biological effectiveness and corrosion related matters the economical aspects (preliminary cost calculations), environmental (impacts through discharge to receiving water, energy consumption, chemical spills, materials used) and risk and safety effects were evaluated. Regarding the economical issues the estimated cost for ultraviolet light was 0.11, ultrasound 0.28 and for ozone 0.22 €/m^3 treated ballast water. Ultrasound treatment increased the water temperature about 5-6 °C. None of the discharges of the methods will include substances identified as "priority hazardous substances". Ultraviolet light and ultrasound treatments require additional pipe lines that may cause breaks and ballast water leaks. Ultraviolet lamps contain mercury that would result in damages in case of breakage. The possible hazard with ozone treatment would encompass larger area since the ballast water is treated in the ballast tanks.

The system configuration utilised in the laboratory scale phases was designed for the macro scale testing on-board. Therefore the available amount of water was insufficient in order to enable a designed function of the devices. Preliminary test phase in Espoo and the Newcastle test trials showed that the apparatus were working as designed when enough water was available. Also the pre-pumping system altered the test results, since it was removed and gravity water supply system was used instead. This arrangement could slightly remedy the source of error but there are still concerns regarding the accuracy of analysis. The lack of pressure caused alterations to the design principles and piping and valves caused errors due to the low flow rates.

Strategy for full scale is based on the experience gained from laboratory scale test trials. The duration of test runs with US and UV will be longer as in laboratory scale tests in order to minimise the technical sources of errors, i.e. piping, fittings, valves and small amount of water. Test trials will take place somewhere in the coast line of Finland with Baltic Sea water. The use of sea water enables the access to unlimited amount of water and thus the error caused by small amount of water can be reduced. Also the link to the actual marine environment is evident. The samples will be taken before and after treatment. Also the strategy with ozone has been changed. The contact time will be extended with modification of the device in order to monitor ozone dosage per amount of water versus contact time. Various ozone dosages and contact times will be studied, possibly also long term test runs might be carried out.

The results from Espoo and Newcastle test trials were partly promising and encouraging but also partly difficult to explain. Therefore ultrasound and ultraviolet systems need to be tested with continuous flow and with duration long enough and also with various pressure levels. Ozone treatment needs to be studied with longer contact times to determine mortality rates versus ozone dosage and contact time. Larger scale test trials are inevitable to find out proper limits for adjustments and efficiency, otherwise the scaling to the full-scale dimension would be very difficult.