

Floating Desalination and Water Pumping Plants as Harmful Algal Bloom Control Technologies

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Abstract

Harmful Algal Blooms (HABs) have significant ecological and economic effects on the marine environment and use. In recent years, researchers have been increasingly developing and testing methods to treat and control HABs. General categories or strategies proposed as HAB control technologies include mechanical, biological, chemical, genetic, and environmental controls.

The authors of this paper suggest using floating desalination plants to treat or control red tides. HAB producing dinoflagellates have been shown to be sensitive to physical and chemical changes in the environment, such as changes in temperature and salinity. The typical response of dinoflagellates is to form cysts that then settle out of the water column.

The discharges from a floating desalination and water pumping plant can rapidly change the temperature and salinity in the water column. These changes could be expected to induce encystment in the dinoflagellate species that form cyst and could cause mortality in those species unable to form temporary cysts. Preventing population growth, inducing encystment, or causing mortality would effectively end a HAB.

Discharges from a desalination plant are temporary in nature and include hypersaline water, freshwater (hyposaline water), and heated warmer. By discharging the heated hyposaline water at a low depth in the water column, due to its lower density than seawater, the discharge would move upward towards the surface. Since the hypersaline water would be denser than seawater, by discharging it at the surface, the hypersaline water would sink. In environments where a stratified water column exists, pumping water could disrupt the stratification without the need for additional desalination. The discharges from a floating desalination plant would stress the red tide with surfacing warmer fresh water and sinking hypersaline water. The stresses caused by these disturbances can disrupt a HAB.

These temperature and salinity changes that could be created by a floating desalination plant would be achieved without the discharge of chemicals or other materials that could have other detrimental environmental impacts. A good aspect of this treatment is that, with continued mixing after discharge, the water would return to ambient temperature and salinity relatively quickly with minimal effect on the marine environment. Since the dinoflagellates have been shown to react quickly to environmental changes, the temperature and salinity of the discharges could be controlled to reduce adverse impacts on other marine organisms. Bench-scale and field tests should establish optimal temperature and salinity ranges for HAB treatment and control.

Keywords: Harmful Algal Blooms (HAB); HAB control; HAB mitigation

Introduction

Harmful Algal Blooms (HABs), commonly referred to as red tides, have significant ecological and economic effects on the marine environment and use. Over the last several decades, there has been a dramatic increase in [1]:

- Areas affected by HABs;
- The number of HABs that have occurred;
- Economic losses attributed to HABs;
- The types of resources affected by HABs;
- The number of toxic species identified as causing HABs; and
- The number of toxins that have been identified in HAB causing species.

Many aspects of HAB ecology have been studied including the processes or mechanisms that lead to the termination of HAB. Potential HAB termination mechanisms include the dispersal of the HAB by

physical advection and the breakdown of the oceanographic fronts that might have originally acted to initiate and perpetrate the HAB [2]. The authors of this paper suggest that the introduction of sudden and significant environmental perturbations could disrupt a HAB and that the introduction of such disruptive perturbations can be used as a mechanism of HAB control.

Researchers have been developing and testing methods to treat and control HABs. However, since HABs are complex oceanographic phenomena, challenges to developing effective HAB control challenge

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measures exist. These challenges include the diversity in the species that create HABs and of the impacts caused by the different types of HABs. As such, investigations into HABs generally require multidisciplinary studies and approaches [1].

Given the complex nature and diversity of HABs, the strategies, needs, and objectives of HAB controls are generally thought to be diverse. Researchers generally feel that HAB control strategies and objectives could vary [1]:

- Between locations;
- Among HAB types;
- To protect fisheries;
- To minimize economic losses;
- To minimize ecosystem impacts; and
- To protect public health.

HAB controls are considered to be the actions taken with the objective to suppress or destroy HABs. HAB control is generally considered to be one the most challenging and controversial aspects of HAB management (1). HAB control technologies can generally be grouped into the following categories or strategies [1]:

- Mechanical control;
- Biological control;
- Chemical control;
- Genetic control; and
- Environmental control.

Several of these technologies or strategies have been applied with varying success to control HAB species. For all of the technologies; there are logistical, regulatory, and environmental issues. Due to the complexity of HABs, the science of HAB control is still considered to be rudimentary and the development of this science is considered to be slow [1].

However, as pasteurization was found to control a number of disease-causative organisms in a number of liquids, the authors of this paper suggest that certain control approaches may be suitable for the control of a wide range of HAB species across a wide-spread geographic range. The authors of this paper suggest that floating desalination and water pumping plants can be used to treat or control HABs.

General Strategy for HAB Control

Research suggests that the dynamics and impacts of HABs are frequently controlled by physiological responses of the causative dinoflagellate with local environmental conditions and by interactions between biological and physical processes that occur over a broad range of temporal and spatial scales [3]. HAB producing dinoflagellates have been shown to be sensitive to physical and chemical changes in the environment, such as changes in temperature and salinity. The typical response of dinoflagellates to environmental perturbations is to form either permanent or temporary cysts that eventually settle out of the water column. Temporary encystment is a survival mechanism by which dinoflagellates respond to sudden or significant environmental perturbations that may be of limited duration. Factors influencing temporary cyst formation include [4-6]:

- Salinity changes;

- Temperature changes;
- Light changes;
- Chemical changes;
- Nutrient depletion; and
- Dissolved oxygen changes.

Permanent cysts are generally the result of sexual reproduction in the dinoflagellates and often accompany the final phases of a HAB.

Given the characteristics of HABs and dinoflagellate life cycles, the primary objectives of HAB control strategies should be as follows:

- Disrupt the environmental conditions that support the persistence and propagation of HABs;
- Stop dinoflagellate cell division and therefore, population growth within the HAB;
- Induce the formation of temporary cyst formation for the dinoflagellates that have this life cycle stage; and
- Most drastically, cause cell mortality in the dinoflagellates that have created the HAB.

Disrupting the environmental conditions that support the HAB may be sufficient, in and of itself, to lead to the termination of the HAB. Without the proper environmental conditions, the cell division and population will decrease rather than continuing to grow. Due to this disruption, without population growth, a HAB would be effectively terminated.

Rather than terminating a HAB, a change in environmental conditions may induce the formation of temporary cysts. After a short encystment period, the dinoflagellates may excyst and, if the disruptions have passed, a HAB could be re-established. The ability of certain dinoflagellate species to form temporary cysts may allow a HAB to become re-established after the application of a potential control technology that is of limited effective duration, such as clay application [7]. A floating desalination and water pumping plant would allow for a HAB area to be continuously or repeatedly treated so that, as the dinoflagellate sex cyst from the temporary cysts, significant environmental perturbations can be reintroduced. Repeated treatments would ensure that the temporary cyst formation and excystment cycle is counter-balanced and terminate a HAB.

In practical terms there are only a limited number of environmental conditions supporting HABs that could be disrupted on a scale to potentially terminate a HAB. The primary conditions that can be disrupted on such a scale are most likely salinity, water temperature, and stratification of the water column. These three parameters can be significantly altered by a floating desalination plant. In areas where a stratified water column exists, a floating water pumping plant could be adequately efficient without the need for a desalination operation.

If the environmental disruption is significant enough, the mortality of the cells in the dinoflagellate population can actually be affected. An extreme form of HAB control would be to cause a die-off of the dinoflagellate cells, which could be achieved through the use of a floating desalination plant. The major challenge of using a floating desalination plant would be to terminate a HAB without causing mortality in other marine organisms. By controlling the salinity and temperature of the discharges from a floating desalination plant, the mortality of other marine organisms should be avoidable while still terminating a HAB.

Floating Desalination and Water Pumping Plant for HAB Control

A floating desalination and water pumping plant is suggested as a potential technology for the control and suppression of a HAB. This control and suppression is possible because the discharges from a floating desalination plant or a water pumping plant could create sudden, large scale environmental perturbations. These environmental perturbations would include:

- Hyper saline discharges;
- Hypo saline - freshwater discharges;
- Heated water discharges; and
- Disrupt water column stratification through advection currents.

The environmental perturbations could induce simultaneous formation of temporary cysts in the species that form temporary cysts. Repetitive discharges from a floating desalination plant could counteract the cyst cycle and prevent the re-establishment of a population of motile, free-swimming dinoflagellates. For both species that form temporary cysts and species that lack this life-cycle stage, the hyper saline, hypo saline, and heated discharges could create conditions that would lead to the ultimate death of the cell, permanently ending a HAB.

A floating desalination plant can cause significant, temporary changes in salinity, water temperature, and water stratification. A floating desalination plant could be designed so that the water intake is near the top, middle, or bottom of the water column. Once the water intake begins, a current would be created, which would begin to disrupt any water stratification that may be present.

After the desalination is completed, there will be a hyper saline discharge and a hypo saline discharge. These discharges will both by heat due to the desalination process. The salinity, temperature, and volume of these discharges can be controlled during the desalination process. Since the hyper saline discharge will have greater density than the ambient conditions, the discharge of the hyper saline water at or near the sea surface will allow the effluent to sink and mix in the water column. If the hyper saline water is cooled before discharge, such as running the hyper saline discharge line inside the line for the cooler intake water, the density difference can be increased, which would enhance the sinking and mixing of the effluent.

The heated, hypo saline discharge will be less dense than the ambient water. This less dense effluent can be discharged at or near the sea bottom and, due to the density difference would rise and mix through the water column. The water intake, hyper saline discharge, and hypo saline discharge will create a complex, dynamic environmental perturbation with rapidly changing water temperature and salinity and a disruption of stratification through currents created by the intake, the discharges, and advection. The creation of such a complex and dynamic environment will destabilize the conditions supporting the HAB and, given the dinoflagellate ecology, is predicted to induce the termination of a HAB.

If a HAB exists in a strongly stratified area, HAB termination could be achieved more simply through a floating water pumping plant without the need for a desalination process. In a strongly stratified water column, the water intake and discharge structures can be placed above and below the thermocline or pycnocline. Similar to a floating desalination plant, a water pumping plant can create currents through

the intake and discharge of the water on either side of the stratified boundary. Currents could also be created through advection due to the discharge of warmer water into a colder water strata and the discharge of colder water into a warmer water strata. Significant environmental perturbations can be caused by significant changes in salinity and water temperature and the disruption of water stratification, leading to the termination of a HAB.

Salinity limitations

All dinoflagellate species have a limited range of salinity tolerance. Both the upper and lower limits of this salinity tolerance range can be surpassed by the hyper saline and hypo saline discharges from a floating desalination plant. In strongly stratified waters, the discharges could also be sufficient to surpass these tolerance limits. For example: *K. brevis* [8]:

- Could not be acclimated to salinities above 45 practical salinity units (psu);
- Could not be acclimated to salinities below 25 psu; and
- Exhibited poor growth poor at salinity above 36psu combined with water temperature above 23°C.

Hyper saline discharges from desalination plants can achieve water salinities greater than the maximum limit while the hypo saline discharges can produce salinities less than the lower limit. Although a water pumping plant will not be able to achieve the extremes of a desalination plant, significant variations in salinity could be obtained.

A concern with discharges from a desalination plant is that the salinities may be at levels that could cause mortality in other marine organisms. However, the salinity of the discharges can be controlled to levels that disrupt the HAB without causing mortality in other marine species.

Water temperature limits

A desalination plant utilizing a distillation process driven by heating the water would result in water discharges that could be significantly above the temperature limits tolerated by the species forming a HAB. For example, in laboratory experiments, all attempts to increase the water temperature to over 30 °C resulted in a rapid death in *K. brevis* cells in the experiments [8]. Additionally, *K. brevis* exhibited poor growth at a salinity greater than 36psu combined with water temperature above 23°C [8]. Therefore, heated discharges, either by themselves or in combination with altered salinity levels could disrupt HABs at a combination of temperatures and salinities that may not cause mortality in other marine organisms. By pumping water in from one side of a thermocline and discharging the water into the opposite side of the thermocline, a water pumping plant may be able to alter the water temperature enough without the need of desalination.

As with salinity, a concern with discharges from a desalination plant is that the water temperature may be at levels that could cause mortality in other marine organisms. However, like salinity, the temperature of the discharges can be controlled to levels that disrupt the HAB without causing mortality in other marine species.

Disrupt stratification

For several species of dinoflagellates, stratification of the water column has been shown to contribute to the formation and propagation of HABs. Research has demonstrated that, in many instances [3,9].

- The development and propagation of certain dinoflagellate

population requires a stable and stratified water column;

- The existence of pycnoclines are a necessary pre condition for the development to certain dinoflagellate populations; and
- Dense *Ceratium furca* populations developed near pycnoclines in Japanese bays.

As discussed above, the water intake, hyper saline discharge and hypo saline discharges can create currents and cause advection and mixing that could disrupt water stratification. If the water column is strongly stratified, the intakes and discharges through a floating water pumping plant may adequately breakdown the water stratification without the added need for desalination.

Floating Desalination Plant – Environmental Impacts

In addition to controlling or terminating a HAB, there are a number of environmental impacts that could be expected from the use of a floating desalination plant. These environmental impacts could include [10,11].

- Increased salinity;
- Decreased salinity;
- Increased temperature;
- Modified water stratification;
- Potential for impingement and/or entrainment; and
- Greenhouse gas and air emissions.

The environmental impacts resulting from the use of a floating desalination plant would be temporary with only a short duration. The mixing of the hyper saline and hypo saline discharges with the marine waters would restore the ambient salinity and temperature conditions. With enough time, water column stratification can be expected to be re-established. In addition, the desalination process could be controlled to limit the salinity and temperature of the discharges to ranges that could disrupt a HAB while limiting the impact on the rest of the marine environment. Unlike other potential mechanisms being evaluated for HAB treatment, such as clay or chemical treatment or the use of biological controls, there would be no foreign chemicals, solids, or biological agents discharged into the environment.

Needed Research

There are several areas of research needed to advance the concept of using a floating desalination or water pumping plant as a HAB control technology. The needed research primarily involves optimization studies and field tests to establish:

- Minimum salinity limits for effective hyper saline discharge;
- Maximum salinity limits for effective hypo saline discharge; and
- Minimum temperatures for effective heated water discharge.

Salinity and temperature tolerances vary between dinoflagellate species and mixing conditions vary with water bodies and marine

conditions. Therefore, the optimization studies and field tests may be needed for numerous HAB species under a variety of conditions.

Conclusions

Sudden and significant environmental perturbations disrupt HABs. A floating desalination plant could be an effective means of HAB control by inducing rapid changes in water temperature, salinity, and stratification. In areas with a stratified water column, a floating water pumping station could disrupt a HAB by temporarily breaking down the water stratification. As a feasible means of HAB control, a floating desalination and water pumping plant would be portable, reusable, and economical.

The expected environmental impacts would be limited in duration and areal extent. Optimization and field studies are needed to maximize the ability to disrupt a HAB while minimizing the adverse impacts on other marine organisms and the marine environment.

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