An Assessment of the Environmental Impact of Brine Disposal in Marine Environment

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Abstract*: The ever increasing demand of water permits the need of alternative water sources for balancing the water supply and demand. Desalination has become a significant alternative water source due to growing demand of water and inadequate conventional water sources in many countries. Desalination is a process of removing excess salts and other dissolved solids from water in order to get clean water for human usage. Brine disposal is one of the major concerns of many environmental issues associated with desalination. The production and growth of marine organisms is severely effected by discharge of brine in the desalination process. These organisms are interrelated with each other so any distraction in their population has extreme impacts on all marine life in the area. In this paper various features of potential impacts of brine effluent in marine environment have been critically reviewed. A relative study on different brine disposal options in reducing these impacts is also prepared in this paper***.

Keywords: *Desalination, Brine, Disposal, Marine Organisms, Environmental Impact*

I. Introduction

The Sustainable development of human and ecosystem health is in threat because of continuous depletion and pollution of freshwater sources (Furumai 2008). The scarcity of fresh water is increasing day by day with the increasing rate of world population, urbanization, pollution and climate change. To maintain the prober balance between water supply and demand, some alternative methods need to be implemented. Water covers three fourth of the earth and 97.5% of this water is saline water (Danoun 2007).One of the most effective alternative methods to utilize of this ample saline water is desalination. Desalination is a process of removing excess salts and other dissolved solids from water in order to get clean water for human usage (Haurwitz et al. 2008). The total process mainly consists of two steps which are evaporation and condensation (Danoun 2007). The three most commercially important desalination technologies are reverse osmosis (RO), multi-stage flash (MSF) and multiple-effect distillation (MED). Reverse osmosis (RO) is one of the latest examples of using membrane technologies. Technological expansion has augmented the efficiency of modern RO plants (Tularam & Ilahee 2007).

Inadequate conventional water sources is the major cause of growing significance of sea water desalination in many countries (Palomar & Losada 2010). Water supply in the middle east and north America profoundly depends on desalination (Haurwitz et al. 2008). Saudi Arabia is the highest producer of desalinated water followed by United States of America (Danoun 2007). Though Australia has the lowest number of desalination facilities (Figure1), the recent water crisis has driven Australia to construct desalination plants. The Goald Coast desalination plant in Queensland, Perth seawater desalination plant in Western Australia and Kurnell desalination plant in New South Wales are currently in use and three desalination plants in Victoria, South Australia and Western Australia are in progress.

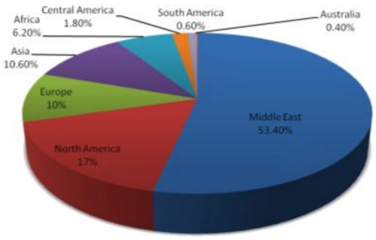

Figure 1: The existing desalination facilities worldwide by region (Source: Modified from International Desalination Association)

There are many issues related to desalination plants that have caused serious anxiety for society and in a bigger extent to the world. High energy is required for desalination processes which result in huge amounts of green house gas emissions. Many environmental issues are associated with desalination. Brine, the concentrated discharge of the desalination process, has serious impacts on the production and growth of marine organisms. The construction process of desalination plants is time consuming and operation and maintenance costs are very high. If the location of the desalination plant is not suitable then it can be inconvenient, loud and disruptive to the environment (Younos 2005) . The release of Carbon monoxide (CO), nitrogen dioxide (NO_2), nitric oxide (NO) and Sulphur dioxide (SO_2) from desalination plants have a detrimental impact on environment at the same time on public health (Al-Mutaz 1991).

1.1 Objectives

To implement a proper desalination plant in a specific area all factors related to desalination need to be identified and examined for that area. This essay will deal with one of the biggest environmental concern of desalination plant – the impact of brine disposal on marine environment. Some arguments will need to be developed related to the environmental impacts to the marine life due to brine discharge. Seawater and water in bays and estuaries is full of organisms like plankton, phytoplankton, larvae and the eggs of marine species. These organisms are correlated with each other so any disruption in their population has extreme impacts on all marine life in the area (Haurwitz et al. 2008). The main objectives of this essay are-

1. To critically review the different features of potential impacts due to brine effluent in the marine environment.
2. A comparative study on the processes which can be used to minimize these environmental impacts

II. Environmental impacts of brine discharge

With the increasing importance of desalination plants, it has become indispensable to review and synthesize various researches that have inspected the environmental and ecological impact of brine discharge on marine environment (Roberts, Johnston & Knott 2010). Many literature reviews have focused on quantify the impact of brine on the physical, chemical as well as biological characteristics of marine environment (RPS 2009). Several published review articles and case studies quote ambiguous peer reviewed literature, and present little or no empirical data to support statements regarding the environmental effects of brine discharge (Roberts, Johnston & Knott 2010). A wide range of potential impacts have been identified due to the brine discharge but only few of the literature scientifically observed the authentic effect of discharge on marine communities around discharge outlets (Skinner 2008).Although so many desalination plants have been constructed in different parts of the world the availability of data on the impacts of their discharge is very little (RPS 2009). The purpose of this review is to identify the physiochemical and ecological impacts of brine on various aspects like temperature, alkalinity, dissolve oxygen, salinity, nutrients and various chemicals of seawater which resultant serious effect on marine environment as well as associated knowledge gaps on this field.

2.1 Temperature

One of the major impacts of brine discharge is thermal pollution which can occur by increasing the temperature of sea water. Numerous studies have been carried out to determine how the distribution and natural balance of marine flora and fauna species respond to an alteration in temperature (Danoun 2007). In these studies a direct correlation between temperature and marine species has been determined. The statements in the previous literatures related to the temperature changes due to desalination remain unclear whether the temperature ranges which were assessed based on field measurements or the model predictions (RPS 2009). The temperature of discharged brine is obviously much higher than the ambient sea water temperature. Temperature of the sea water generally varies between 10ºc to 25ºc which increases about 60% to 40ºc near the area of the brine disposal (Danoun 2007). Alteration of temperature basically depends on the type of the treatment plants. Distillation plants increase the temperature more than the reverse osmosis process. Abdul-Wahab illustrated a direct connection between the temperature of the seawater and the distance from the discharge site (Wahab 2007). The distribution and extent of the temperature alteration also depends on the location of the plant discharge. If the brine discharges in a well-flushed environment, it is more efficient and effective than the brine discharges near to the water bodies(Roberts, Johnston & Knott 2010).

2.2 Salinity

A variety of published literatures and readings disclose the effect of brine on the salinity of the seawater and the resultant impact on marine environment. The centre of attention of these studies is the concentration and expansion of brine plumes on the receiving water (Roberts, Johnston & Knott 2010). It is now widely recognized that extensive brine discharge, as it constitutes a hypersaline layer that sinks towards the seabed due to its greater density, has the potential to heavily affect local marine biota (Medeazza 2005). Changes of salinity influence the propagation activity of the marine species and that consequentially affect their development and growth rate. Larval stages are very crucial transition periods for marine species and increasing salinity disrupts that period significantly (Neuparth, Costa & Costa 2002). Although marine species of the saline water are familiar to this fluctuation of salinity concentrations but they may not survive on this sudden augmentation of salinity because of brine disposal (Haurwitz et al. 2008). As discharged brine is much denser than the seawater so brine plumes have the affinity to extend further along the seafloor than the surface which contributes to greater exposure of benthic organisms to brine discharges, than pelagic and plank tonic organisms (Roberts, Johnston & Knott 2010). Though reverse osmosis processes do not impact much on the alteration of temperature, brine discharges from this process increase the salinity by twice that of the seawater (Tularam & Ilahee 2007). According to several studies the excess salinity level of seawater from brine discharge is directly correlated with the distance of the plant site. It shows that rising the salinity level up to 50 ppt could probably have an serious impact on the fish size and on their survival rate(Parry 1960).

2.3 Dissolve Oxygen

Brine disposal also has an effect on the dissolved oxygen of the seawater. As the amount of dissolve oxygen is inversely proportional to the salinity level, so with the increasing rate of salinity dissolve oxygen is decreasing which consequences hypoxia (Haurwitz et al. 2008). Hypoxia is a serious condition which results from low levels of dissolved oxygen and can cause serious harm to the aquatic organisms. According to report of California Coastal commission,2004 if the temperature of water increases because of brine this can decrease dissolved oxygen and increase biomass resulting from the disposal of entrained organisms (California Coastal Commission 2004; Haurwitz et al. 2008). In reverse osmosis processes temperature is not varied much so major changes in dissolve oxygen due to heating is very unlikely. Though mixing of oxygen consuming chemicals in RO plants to restrain corrosion and eliminate residual chlorine can reduce the dissolve oxygen (Lattemann & Höpner 2008).

2.4 Other Aspects
High total alkalinity is another big impact of brine discharge which increases the amount of calcium carbonate, calcium sulphate and other elements of the sea water twice to its normal level. Very few experiments have been conducted to quantify the alteration of the total alkalinity in seawater due to brine disposal and also the tolerance limit of marine life to it (Danoun 2007). The pH range of marine environments is also changing due to the brine discharge but that is very negligible compared to the other impacts (Skinner 2008). For the proper performance of desalination plants pre and post treatment processes are required whereby many chemicals are added to enhance flocculation or to avoid membrane deterioration. Antiscaling agents like polyphosphates, polymers of maleic acid, sulphuric acid and antifoaming agents like fatty acids, alkylated polyglycoles etc are used as chemical components which are discharged with brine and effect the marine species around the outlet (Medeazza 2005). Many field based monitoring and laboratory based experiment have been implemented to enumerate the ecological impact of the brine disposal.

2.5 Impingement and Entrainment
Some desalination plants need to have substantial intake of sea water which can be harmful for marine species in two ways- impingement and entrainment. Impingement refers to the collision with screen and entrainment refers to the drawn in to the plant (Lattemann & Höpner 2008). When organisms are dragged into an intake pipe and trapped in a fish screen covering the intake which cause injury or death then that is defined as impingement. Entrainment occurs when little organisms pass through the fish screen and are actually taken into the intake pipes (Haurwitz et al. 2008, p. 8).Many previous studies show that these are not threatening for the large species because of small flow rate but smaller animals like phytoplankton, zooplankton can be impinged or entrained.

2.6 Research Gaps
The main focus of this essay is on the environmental impacts caused by the brine disposal on marine environment so this review part consists of various aspects of impacts grounded because of the discharges of desalination plant. But still there are many studies in the literature which are ambiguous as well as unscientific. Some literature has tried to define the positive and negative impact both which is very much contradictory. According to Rashad Danoun, alteration of temperature can have an influence on the production rate as well as life span of the marine species which can be decreased with the increasing rate of temperature. But in the other part he has tried to portray the positive aspect by saying that increased temperature of the ambient environment leads to a positive effect on growth rate of several species of plankton (Danoun 2007). Neither very specific nor very reliable temperature ranges can be set for desalination plants. One of the prominent reasons for this is the difference between field measurement and model predictions. There is still some lack in previous investigations of the documentation of experimental data of temperature change which is affecting the marine flora and fauna. Many mathematical models have been created to inspect the salinity level in sea water. Though brine flume has the potential effect on the salinity level of sea water but other causes of rising salinity like irrigational flow, breakdown of rocks and minerals, locked down of freshwater in to the ice caps etc. also need to be taken in consideration. The salinity of bay and estuaries can also be increased by low flow of fresh water from rivers due to increased Water Rights. The previous studies have not included all these factors in conducting comparative study of rising condition of salinity level. It is stated before in many readings that salinity level and the location of the plant is correlated and salinity declines rapidly close to the outfall of the desalination plants. But precise measurements are not located in the reviews. This is a big knowledge gap because accurate distance could help to locate the suitable site for the desalination plant. In most of the previous literatures, the effect of reduced level of dissolved oxygen has been analysed for a particular plant not for different desalination plants. But with the diverse locations of plants, impact of dissolved oxygen in the receiving water can be changed. Impact on the small marine species due to brine discharge has been assessed in lots of literatures but less information is available about the large marine fauna. Impingement and entrainment are very new explored ideas and most of the desalination plants were established without considering these impacts. So, these knowledge gaps need to be overcome for the betterment of desalination system.

III. Impact minimisation
Currently the increasing rate of practice of desalination plant has led to the development of many new methods and options to minimize the impact of brine disposal. While there are many options available for minimising the impacts of brine disposal, different strategies are appropriate only for different locations. So, before using the strategy, it needs to be evaluated both environmentally and economically (SOL-BRINE 2009).In this section of the essay, different minimizing process will be depicted and some recommendations will be suggested with respect to the various conditions of the sites.
The alternative options of brine disposal can be divided in to three different categories.

1. Changing the location of brine disposal/ Treatment before discharge
2. Redesigning the desalination plant
3. Coupling the desalination plant with some existing treatment plant

3.1 Changing the location of the brine disposal/ Treatment before discharge

By changing the location of brine disposal and treating the brine before ultimate discharge the actual impact of brine in the receiving water can be reduced. Brine can be discharged in the surface water and diluted by outfall diffusion devices like diffusion nozzles or can be mixed with less saline waste streams before ultimate discharge. However this option can only be used when surface water body is located nearby to the estuary (Castillo, Sanchez & Castillo 2007; Sarté et al. 2006).Brine can be directed to the existing sewer treatment plant to dilute with municipal wastewater prior discharge. However volume and composition of the brine, the convey process and reaction of the brine with the waste water need to be taken into consideration (SOL-BRINE 2009). The High range of dissolved solids of the waste water could be of great concern for marine environments when treated water is released back into the seawater. Injecting brine via wells into confined and non-potable aquifer systems can also be a good option of disposing brine. It is important to have a monitoring well near the injection well to assure that there is no leakage from the injection well. As it naturally pre-filtrates the feed water, it lowers the saline water table (Lattemann & Höpner 2008). This option is not cost-effective because of the construction of an extra well and groundwater infectivity can be occurred because of mechanical collapse of the injection process and over pressurization resulting from the high injection rate (Haurwitz et al. 2008). Spreading brine in shallow ponds where it gradually evaporates, the concept of evaporation pond, can also be a suitable mitigation measure (Sarté et al. 2006). The residual solid that is left behind in the pond can be used for landfill or collected for re use. Solid lining or monitoring wells may be required to ensure that ponds do not drip and pollute surrounding soils or aquifers (Haurwitz et al. 2008). This process is land intensive and also cause significant loss of the basic water resource through evaporation (Younos 2005). Each of these conventional strategies is more suitable for small and medium size facilities. However these processes can reduce the salinity level of the brine so after discharging brine will not be as much harmful for marine biota.

3.2 Redesigning the desalination plant

Environmental impacts can be mitigated if the desalination plant can be designed in a sustainable way or some essential parts or mechanisms can be included or installed. Beach wells or infiltration galleries can be installed which drag in seawater through the overlying substrate. This overlying substrate works as a natural filter to keep out small marine creatures and larvae. This can improve the quality of feedwater and reduce the cost for pre-treatment. Impingement and entrainment can also be minimized by this process (Haurwitz et al. 2008). Historically 'jet' of brine released at 60° angle was adopted as standard design criteria. Recent modelling approaches has proved that shallower discharge angle 30°-45° may enhance mixing and offshore transport of desalination brines in coastal waters with moderate-to-steep bottom slopes (Jirka 2008). This can minimise the spatial extent and intensity of brine plumes which results in reduction of salinity level. Now days jetties have been constructed adjoining to the desalination plant discharges to create offshore currents which can minimize the extend of brine plumes and persuade more rapid mixing (Roberts, Johnston & Knott 2010). Advancement of nanotechnology helps to create devices and systems by using nanostructured materials like carbon nanotubes, nanowires, graphene, quantum dots, super lattices, and nano shells for desalination technology. It is Useful to separate water from salt , control the evaporation and produce next generation RO membrane (Humplik et al. 2011). Another useful system can be developing anti scaling with no biological effect by using the scale inhibitors which may assist in the production of less toxic brines in the future(Ketsetzi, Stathoulopoulou & Demadis 2008). Further research is required to understand how these techniques can be properly utilized as these are very new approaches.

3.3 Coupling the desalination plant with existing treatment plant

Desalination plants can be co located or coupled with some existing treatment plant like power plant, and salt works which can also be very useful in mitigating the impact of brine. Desalination plants can be co located with older thermocouple plant to dilute the brine with power-plant cooling water (Roberts, Johnston & Knott 2010). These options should be considered for larger plants which would limit the brine plume to be extended far and reduce its effect in receiving water (Einav & Lokiec 2003). Cooling systems are very efficient for reducing impingement and entrainment, construction problems, land use impacts and usage of chemicals (Lattemann & Höpner 2008). The desalination plant can be coupled with solar salt works by directing the brine to a salt works for brine concentration and salt production with an aim of achieving zero discharge desalination plant. Extra salt can be produced by using this process in the factories which results extra income and also minimize the transportation cost(Laspidou, Hadjibiros & Gialis 2010).

3.4 Recommendations

All these strategies cannot be suitable for every location. Suitability of the options can vary because of the location of the desalination plant-nearby or far from coast, land uses of the adjacent places of the plant, availability of idle lands, energy emitting system of the plant and also the other associated aspects of desalination. Some recommendations are made based on the previous literatures and knowledge and experience acquired by assessing various minimizing processes. For desalination plants using membrane technology, zero liquid discharge process can be a very efficient alternative option. ZLD is actually a thermal evaporative system which can reduce volume of discharge by using thermal evaporators like crystallizers, spray dryers etc. Though these processes are expensive and energy intensive which can be counterbalanced by modernizing the membrane system. Those areas where enough lands are available evaporation ponds with aquaculture and agricultural application may be worked as economically viable. Black bream, snapper, Dunaliella, brine shrimp can be successfully raised in the brine and plants tolerant to high salinity can be irrigated nearby to the evaporation pond. The land cost, monitoring cost, and lining cost related to evaporation pond can be minimized by production of fishes, plants and salts. For arid regions like Australia, evaporation ponds can be a useful option when availability of land is enough. Salinity gradient solar pond is also a possible synergy for the evaporation pond which joins the collection of solar energy with long-term storage and produce electricity (Svensson 2005)This can reduce the electricity problem of Australia in a greater extent. If impacts cannot be minimized by using different strategies or systems, then site of least impacted needs to be identified. If enough investment is ensured then nanostructured material, anti scalant can be used in the desalination plant. These new inventions are expensive but much more valuable for reducing impacts than the conventional processes. Researchers have now invented a new process of brine management that is effective for both inland and coastal desalination plant. Solvay process is actually developed to convert the brine into reusable solid product Sodium Carbonate. It is executed by mixing the reject brine (saturated sodium chloride solution) with carbon dioxide and ammonia in a high temperature to get sodium carbonate as final product and water (El-Naas 2010). These new technologies can be very functional for Gold coast and Kurnell desalination plant of Australia as severe environmental impact of brine is being revealed there

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IV. Limitations

Though several literatures are critically reviewed and analysed on this broad area of desalination, but there are some limitations of this study which requires to be emphasized more. In the literature review a wide range of impacts and their associated risks has been identified but enough data could not be analysed from laboratory-based experiments or toxicological investigations. These data could have been more useful to practically illustrate the adverse impacts of brine on marine organisms. Recommendations that have been made to mitigate the impact needs more experiments and investigations for specific regions. Irrigation of saline tolerant plant can be useful but at the time of heavy rainfall other processes need to be available. So, seasonal fluctuations were needed to be taken in to account. Economic viability of the recommended processes is not taken in to account properly which is significant from the view of decision makers. No modelling results have been used to identify proper location of brine disposal. But, modelling the plume of brine is recommended to demonstrate the dispersion area. Water quality test of the concentrated brine is essential with respect to the different factors like- temperature, salinity, dissolved oxygen, alkalinity etc. to validate the damage these could cause to the marine environment. This essay has provided overall idea about various mitigation measures but individual study is required on every process before implementation. So, experiments and case studies are required in small scale of the conventional and recommended measures to identify their suitability in large scale. Monitoring program for long term is suggested nearby to the coastal area to investigate the actual impact which may be altered with time.

V. Conclusion

With the increasing rate of water demand, desalination is now being used as an important alternative option of clean water supply. Because of this high demand of water marine environmental problems related with desalination have always been considered as secondary concern. Marine species are severely impacted by the brine disposal without proper treatment. In some cases the impact rate may be huge or in other cases it may be low. But, this impact is little regarding to the high substantial alteration of sea water because of physical and chemical changes. Other negative aspects of desalination like high energy usage, GHG emissions, huge O&M cost etc. are much more significant relative to impact of brine. Mitigation measures for these impacts are needed to be selected with respect to the suitability of the plant and conditional attributes of the particular area. Some new inventions are discussed in this essay for design, location and measurement of desalination plants to minimise or eliminate any potential impacts of brine. New technological ideas and materials are desirable to lower the impact and keep a well coastal marine environment.

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