# DESALINATION USING ACRYLIC ACID BASED HYDROGELS

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**Abstract**- The following report discusses acrylic acid-based hydrogel beads and their potential use for the process of desalination. The report explains the mechanism of the hydrogel beads and describes the advantages of using hydrogels compared to various other desalination processes such as multi-effect evaporator, reverse osmosis and forward osmosis. The results included in this report are developed concentration profiles for tap water, concentration profiles at various temperatures from a range of 30 to 55℃, and concentration profiles at alkaline pH values. When placing the beads in solution, there is a higher increase in the concentration of tap water compared to sea water. At elevated temperatures, the beads have a higher absorption rate and show increased concentration readings. At a temperature range of 30 – 40℃, the hydrogels turn hydrophobic and release water and thus yield lower concentrations. The absorption rate of the hydrogel beads increases with alkaline pH values. However, acidic pH values again force the hydrogels to release water and thus can be used as a method to recover clean water stored inside the bead. Four other methods to recover water are also explained. These include, copper sulfate draw solution, drying (evaporation and condensation), ethanol draw solution and sunlight tubes. The report concludes with a summary of all experimental lab-scale results conducted in the lab to investigate desalination using acrylic acid-based hydrogel beads.

## I. INTRODUCTION

Water is an essential element for the existence on life for all living things. Many parts of the world face clean and desalinated water scarcity. In the UAE, there is a lack of fresh water resources. To meet this ever expanding demand for drinkable water in UAE, water treatment has been a subject of intense study. Realizing the importance and expanding demand of water for mankind and industry worldwide, desalination is possible using the new technology of the acrylic hydrogel beads for water desalination. Hydrogels are three-dimensionally cross linked polymers which are hydrophilic in nature [1], as shown in Figure 1 and 2. They come in a variety of compositions which enables them to absorb different amounts of water, until they become fully saturated. Their high porosity makes the water absorption possible.



**Figure 1: Increase in size of hydrogels**

They have a wide variety of applications for different purposes mainly including: gardening applications, decoration purposes, and biomedical engineering applications. As the hydrogels expand, they undergo a volume phase change, which can be influenced or manipulated under different environmental conditions including: temperature, pH of solution, ionic concentrations, and salt concentration [2]. Hydrogels are usually inserted in a water solution in which they will expand and swell as they take in the water. In gardening, the beads should be kept close to the plant roots due to the fact that the water will be released from the beads after some time. This is to ensure that drought will not occur as the stored water is released directly to the plants' roots [1]. In biomedical engineering, the hydrogels are used in the making of contact lenses, as shown in figure 4 [3]. In addition to that, it is used on deep wounds, as it can be designed to absorb the toxins and moisture in order to prevent it from contaminating the wounded area, and in order for it to prevent the wounded area from heating up excessively [3]. Furthermore, the hydrogels can also be used in absorbing drugs and transporting them to the human body for later release. The drug can then be released after some time by diffusion [3]. Also, hydrogels are used in case of tissue damage or loss as they can replace lost tissues by acting as fillings in the required spaces [3].

For this project, however, the hydrogels are used in the desalination of salty water under various environmental conditions. Temperature, salt concentration and pH was varied and different runs were taken. Throughout the runs, the TDS, or total dissolved solids, were measured and the time intervals were recorded in the discussion section of the report. Despite the multi-applications of these beads, they are considered very cheap, as they do not require usage of any form of energy.

### 2.1. Hydrogel Desalination Mechanism

When placed in a salt solution, water is drawn into the acrylic acid-based hydrogels due to osmotic potential while the salt ions are partly rejected and remain in the solution (Figure 2). This is due to a high charge density within the hydrogel which enables water uptake and prevents ions from entering due to electrostatic interactions [4].

Once maximum saturation is obtained, water present inside the hydrogel needs to be removed. The water obtained will have a much lower salt concentration than initially and thus constitutes the first successful desalination step. Several cycles may be used to achieve desired water concentration [4].

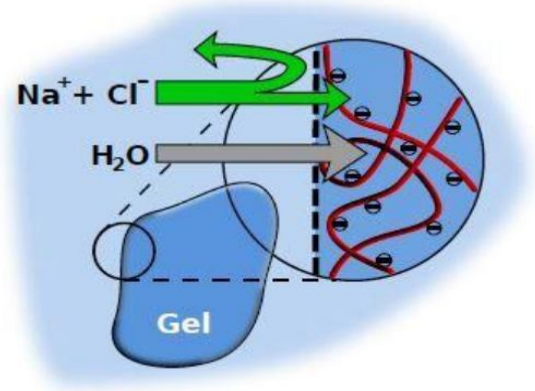


**Figure 2: Hydrogel Desalination Mechanism**

### 2.2 Hydrogel Desalination vs. Traditional Desalination

Table 1 shows a comparison between the various desalination methods available versus desalination using acrylic-acid based hydrogels.

As seen, the energy requirements, equipment costs and equipment complexity are all low for the hydrogel method. Discussed below are the disadvantages of the alternative traditional desalination methods.

- Reverse Osmosis has a high energy requirement of 3 – 5.5 kWh/m3 [5]. It also expensive and requires high pressure. As reverse osmosis is membrane technology, the membranes are prone to fouling and clogging and need to be backwashed to clear the pores.
- Forward Osmosis is a relatively new method still under research and development. It has low productivity and requires energy to recover clean water. Forward osmosis also has a lack of robust membranes.
- Multi-effect evaporators also have a very high energy consumption of 6.5 – 11 kWh/m3 [5]. They are expensive membrane technology and thus require high pressure and are prone to clogging and fouling.
- Multi-stage flash distillation (MSF) the first commercial desalination technique that have been used. It is mainly favored due to its large-scale operations and good potable water quality with 5 to 50 TDS range. Nevertheless, the pumping power needed for the operation of the MSF systems is 2 to 3.5 KWh/m3 of produced water.

Conducting desalination using hydrogels on the other hand is a cost effective and environmentally friendly process. It uses consumes 0% of energy, does not require expensive membrane technology, and therefore has a low operation cost. This method also does not require any sort of piping system and is efficiently reusable

**Table 1: Comparison of Desalination Methods**

| | Reverse Osmosis | Forward Osmosis | Multi-Effect Evaporator | Acrylic Acid-Based Hydrogels |
|---|---|---|---|---|
| **Energy Requirements** | High | Moderate | Very High | Low |
| **Equipment Cost** | High | Low | High | Low |
| **Equipment Complexity** | High | High | Very High | Low |

## II. MATERIALS AND METHODS

The experimental procedure followed is very simple and based on bench scale test. In this case, a synthetic salty solution at given concentration.is prepared. After, certain amount of hydrogel is transferred into the solution and over time, the TDS and pH of the solution were measure until steady state is achieved.

A TDS meter indicated the amount of total dissolved solids in a solution. This device was used to measure the concentration of a solution in parts per million (ppm). The pH meter was used to measure the pH i.e. the acidity or alkalinity of a solution. A digital thermometer was used to measure the temperature of solutions for lab-scale experiments done at various temperatures. Heating mantles were used to heat the solutions in the beaker.

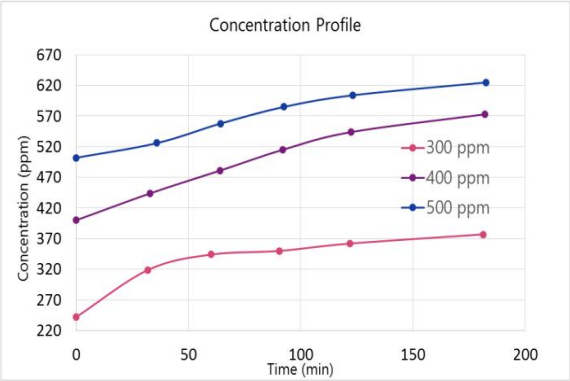


**Figure 3: Concentration versus time at different initial salt concentration**

## III. RESULTS AND DISCUSSION

3.1 Concentration Profile. To investigate the mechanism of acrylic acid based hydrogels, a concentration profile was developed. Three samples with initial concentration 242 ppm, 400 ppm and 502 ppm were used. The hydrogels were then put into the samples of size 250 ml and the concentration was monitored every 30 minutes. The results are shown in Figure 3 which indicates that concentration increases with time. After 3 hours, the concentration increased to 377 ppm, 573 ppm and 625 ppm, respectively. This is approximately 1.4 times the initial value. This demonstrates that hydrogels absorb water while leaving the salt ions in the solution.

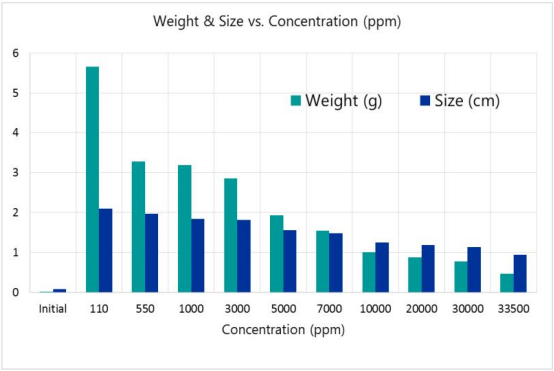


**Figure 4: Weight and size of the gel at Different Concentrations**

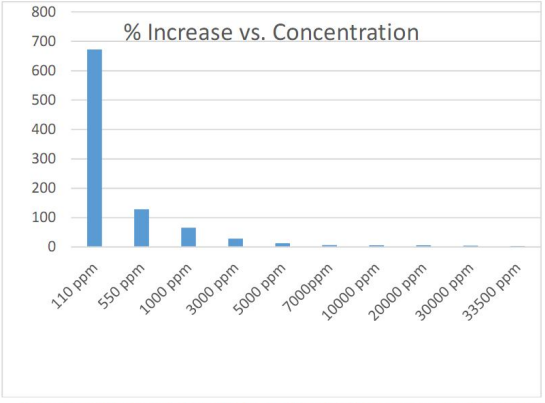


**Figure 5: Percent increase in concentration versus concentration.**

**3.2 Weight and size versus concentration**. The effect of different concentrations on the amount of water absorbed by hydrogels was investigated. This was done by preparing solutions of different concentrations and placing hydrogels in them. The results were observed after 2 days. Figure 4 demonstrates that as the concentration of the water sample increases, the weight decreases. The initial weight of the sample was 0.00978 g. It can be seen that for 110 ppm, the final weight was 5.66 g while for the sample with 33500 ppm, the weight only increased to 0.468g. Moreover, it was observed that the increase in size also reduces as the concentration of
the water sample increases. The initial size of the hydrogel bead was 0.0884 cm. It increased
to 2.1 cm for 110 ppm and only increased to 0.944 cm for 33500 ppm. Figure 5 demonstrates that the percentage increase in concentration is higher for samples with lower initial concentration. For example, the concentration for drinkable water increased from 110 ppm to 850 ppm showing a % increase of 670 %. Whereas, the concentration of the sample with 33500 ppm only increased to 34500 ppm showing a % increase of 2.99%. Therefore, as the concentration of the water sample increases, the amount of water absorbed decreases. This is due to the fact that the hydrogel mechanism slows down at higher concentrations making it harder to absorb water. Moreover, hydrogel has a maximum absorption capacity. As the concentration of
salt becomes really high in solution some of the salt may be absorbed by the hydrogel beads which causes blockage and thus
hydrogel cannot absorb any more water.

3.3 Effect of pH. Figure 6 displays a concentration profile at pH values of 7, 7.6, 8.2, 8.8 and 9.1. The initial TDS of all the samples was measured to be 115 ppm. It can be seen that samples with higher pH value resulted in higher concentration. It can also be seen that samples with pH of 9.1 gave the highest final concentration of 150 ppm when compared to a lower pH value of 7.0 which shows a final concentration of 120 ppm. Therefore, it can be concluded that the absorption rate increase is faster with highly alkaline samples. An alkaline sample may cause the pore size of the hydrogels to increase and thus it is able to absorb more water in comparison.

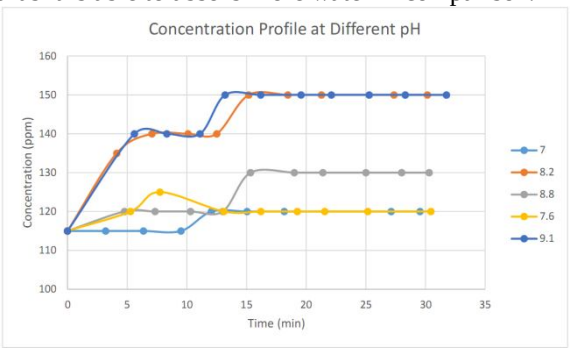


**Figure 6: Concentration profiles at different pH values.**

3.4 Water Recovery Methods. After the hydrogels have absorbed the relatively pure water, it has to be

recovered from the gel. This is one of the main obstacles faced for this method of water desalination. Several, relatively economical, methods have been proposed.

A novel method to recover water out of the hydrogels would be to use copper sulfate as a draw solution. Lab tests were carried out for this technique. Saturated hydrogels were placed in a copper sulfate solution which was placed on a magnetic mixer. The hypotheses for this method was that the water would be released from the gel due to a concentration gradient. The TDS was measured for this solution at regular intervals at it was found to increase; it can thus, be concluded that the gels released water into the draw solution. However, there are certain drawbacks to this technique:

- The method for separation of the draw solution from the water was inconclusive. It would be energy-intensive or would require the use of further raw material.
- The reusability of the hydrogels was tested by use over several cycles. It was determined that the hydrogels absorbed the draw solution, while releasing the water from the polymer (the gels turned blue). This meant that the hydrogels could not be used several times leading to increased raw material costs.

It was thus concluded that this method required further research and was not a desirable solution to recovering water from the polymer.

Another proposed method for recovery of water from the polymer was the use of ethanol draw solution. The same hypotheses were proposed as for the copper sulfate draw solution. Lab tests for the proposed method were carried out as follows:

1. Four ethanol solutions of 80%, 70%, 60% and 50% by volume were prepared.

2. Saturated hydrogels were added to the draw solution simultaneously.

3. Concentrations of each solution were measured at regular intervals (an average of 10 minutes). A concentration profile was developed for this method.

4. The hydrogels size was observed over a period 5 days.

5. Distillation was carried out on the 80% by volume draw solution with the recovered water in it.

The results are shown in Table 2. It can be seen that the TDS of the ethanol draw solution increased with time. It can be deduced from these data that the hydrogels are releasing more water into the solution. The highest initial waster release was observed for the 50% ethanol solution. The difference between the initial and final TDS values, as depicted from Table 2, was calculated; for the 50% ethanol solution to be 178 ppm, the 60% ethanol solution was 191, the 70% ethanol solution was 197 ppm, and the 80% ethanol solution was 189 ppm (at 60 minutes). Therefore, it can be concluded that the 70% ethanol solution can be considered as the best solution to be used as draw solution. Thus, it is noted there is no significant difference in the amount of TDS removal for all four solutions.

After recovery of water using the solution, the next step was to separate the ethanol-water mixture using single-stage distillation. This was done for the 80% ethanol-water solution and the results for this lab test were inconclusive. For further work, it is suggested to use distillation to check the composition of water in the 60 and 70% ethanol solutions.

**Table 2: Water recovery using ethanol as draw Solution**

| | Ethanol Solution (% volume) | | | |
|---|---|---|---|---|
| | 50% | **60%** | **70%** | **80%** |
| Time (min) | TDS (ppm) | TDS (ppm) | TDS (ppm) | TDS (ppm) |
| 0 | 83 | 61 | 43 | 27 |
| 20 | 208 | 197 | 168 | 138 |
| 25 | 223 | 219 | 197 | 167 |
| 35 | 240 | 230 | 222 | 176 |
| 55 | 245 | 240 | 230 | 210 |
| 60 | 261 | 252 | 240 | 216 |

Another method to recover water from the hydrogels would be to evaporate the water from the saturated hydrogels by evaporation. The water can then be condensed to obtain pure water. Since this process can be carried out at ambient temperatures in the U.A.E., it is not energy-intensive. Lab tests were carried out for temperatures of 30 ℃ and 50℃ and the water was recovered. Furthermore, the hydrogels went back to their initial size after all the water was evaporated. The absorption and desorption of water was performed 13 times. Therefore, it can be deduced that the hydrogels are reusable.

## CONCLUSION

The performance of hydrogels was analyzed in the lab using different concentration profiles of sea water and tap water. Based on the results obtained in this work, it can be concluded that at a higher temperature the pore size of the acidic hydrogel beads increases, thus being able to absorb more water and leave out salt ions. The absorption rate increases at elevated temperatures. The absorption rate increase is faster with highly alkaline samples. An alkaline sample may cause the pore size of the hydrogels to increase and thus it is able to absorb more water in comparison. From the experimental results obtained, it can be concluded that water absorption using hydrogels is a cost-effective and an environmentally friendly process with zero energy consumption in order to produce potable water from sea water.

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