



KAIROSPACE
TECHNOLOGIES

Preliminary Heat Transfer Validation Experiment V1.2.1

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Introduction

This document will discuss in detail the hypothesis, methodology, experimental procedure, data analysis and results of the preliminary heat transfer validation experiment conducted by the Kairospace engineering team.

Water has been traditionally used as a coolant because of its high specific heat, which, as compared to other liquids, allows for the removal of vast amounts of heat. This phenomenon is remarkable and is used in myriad of applications ranging from small scale (e.g., consumer electronics) to large scale cooling (e.g., HVAC systems in large buildings or large-scale industrial settings like power plants). Applications in CEA, livestock, and mining operations are also of interest.

Because of the increasing scarcity of water as a resource, it is important to study how we can use water for cooling more efficiently and minimize waste while maintaining or increasing efficiency.

Hypothesis

Our hypothesis is that introducing dissolved oxygen and/or other atmospheric gases into water will increase the amount of heat that such treated water can remove.

Kairospace has developed a method of performing advanced water treatment resulting in the incorporation of ultra-fine bubbles into the treated water. Ultra-fine bubbles (UFB) can be up to

500 times smaller than microbubbles resulting in over 400 times more surface area in given volumes. This increase in the surface area is ultimately what leads to a more efficient and effective energy transfer, suggesting that incorporating the UFB into water will increase the heat transfer efficiency of such treated water. To treat the water, we have utilized our AG-PACK machine which can be seen in Figure 1.

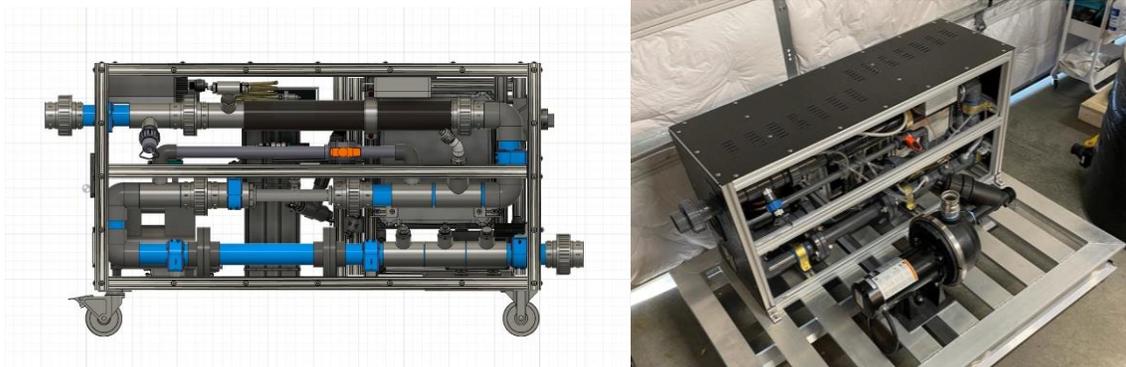


Figure 1: A side-by-side comparison of the AG-PACK module used to treat the water for this experiment. On the left is a CAD rendering at scale, and on the right a photograph of the constructed system.

The AG-PACK module is designed as an advanced water treatment platform capable of efficiently generating dissolved gases inside of a water circuit. It should be noted that this AG-PACK treatment module is designed for multiple application schemes in various technical settings; however, much of the auxiliary hardware involved can be reduced or eliminated to achieve comparable results with less power consumption, as reported herein.

The recirculating treatment system operates within the following specifications and features:

- Temperature of Operation: 0-40 degrees Celsius
- Humidity: 10-80%
- Machine Dimensions: 44x60" (pallet skid configuration)
- Capacity: 40 GPM
- Power Consumption: 2.8KW continuous running
- Electrical Requirements: 230vac single phase, 30amps, 3 prong GFCI outlet plug
- KS AG-PACK Features:
 - 2" NPT plug and play in-line installation: camlock flex-hose fitting to existing pumps and water circuits. Simple connection of intake and discharge hoses to fill reservoir tanks commonly used in water treatment.
 - Configured for open and closed-loop systems, for single-pass treatment or recirculation.
 - Pressurized auxiliary output port for low flow chamber applications. Includes 3/4 connection with variable 1-4gpm @ 10psi.
 - Equipped with an oxygen concentrator (8 LPM) and ozone generator (10 gr/hr) for high-efficiency liquid-gas mixing and delivery.
 - Equipped with (1/2" female NPT) aux gas port for connecting external gas injection sources (i.e., CO₂ / atmospheric air/gas) for controlling pH and DO levels with precision.

- Digitally integrated automation and sensor controls, for monitoring dissolved oxygen levels in real-time (sensor description: Thermo Scientific AquaSensors, dissolved oxygen sensor uses the amperometric measurement technique to maximize lifetime in continuous industrial applications, pH, ORP, conductivity sensor head adaptable.)
- Adjustable DO supersaturation settings (9-45ppm).

Materials

Experiments were conducted using a custom fabricated chamber consisting of a rectangular glass tube held between two aluminum plates as seen in Figure 2.

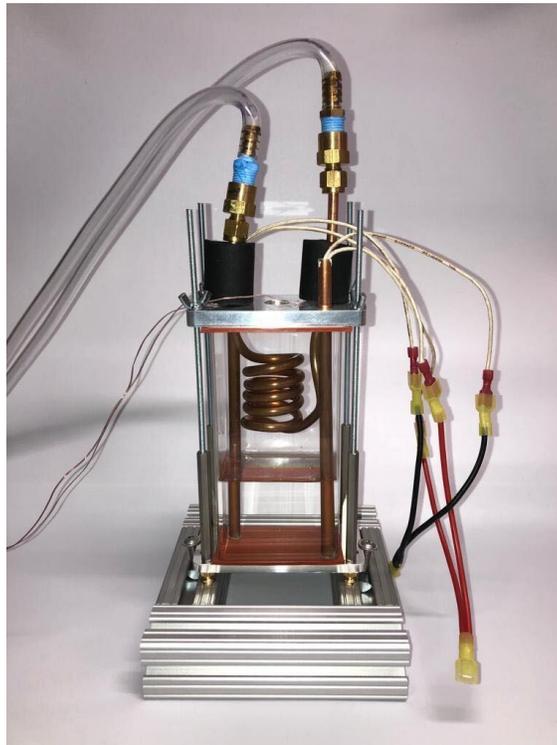


Figure 2: Heating chamber utilized for the experiment. Visible is the copper coil used for condensing as well as the two copper rods holding the cartridge heaters used for heating the fluid in the chamber.

The heating in the chamber occurs through a pair of insertion cartridge heaters positioned inside two copper tubes sealed on one side using copper foil. These heaters were powered using a pair of voltage-controlled, DC power supplies. In addition to the boiling chamber, a Naudacaa Industrial Water recirculation chiller was used. See Figure 3.

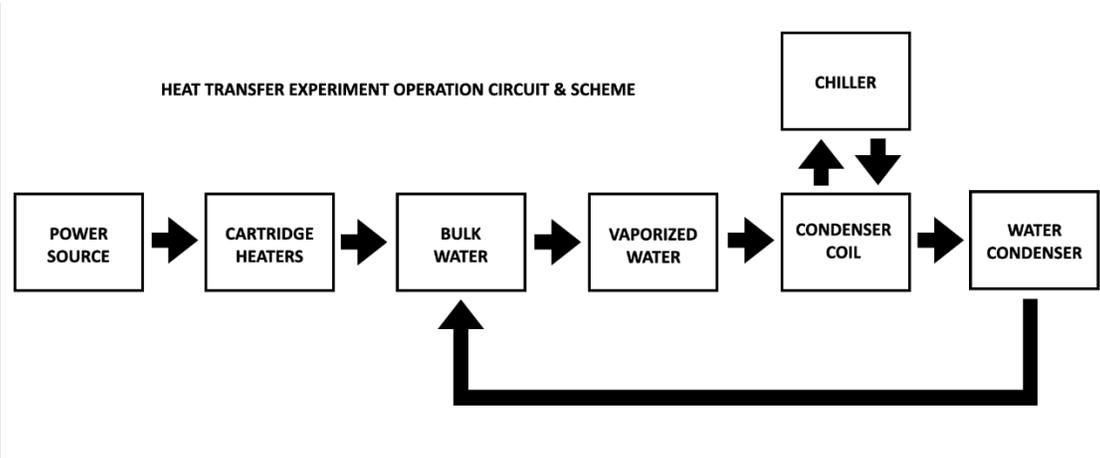


Figure 3: Heat transfer experiment operation circuit and scheme.

Sampling

Treated bulk water samples are rendered using the AG PACK WATER RECIRCULATION MODULE PROCESS. See Figure 4.

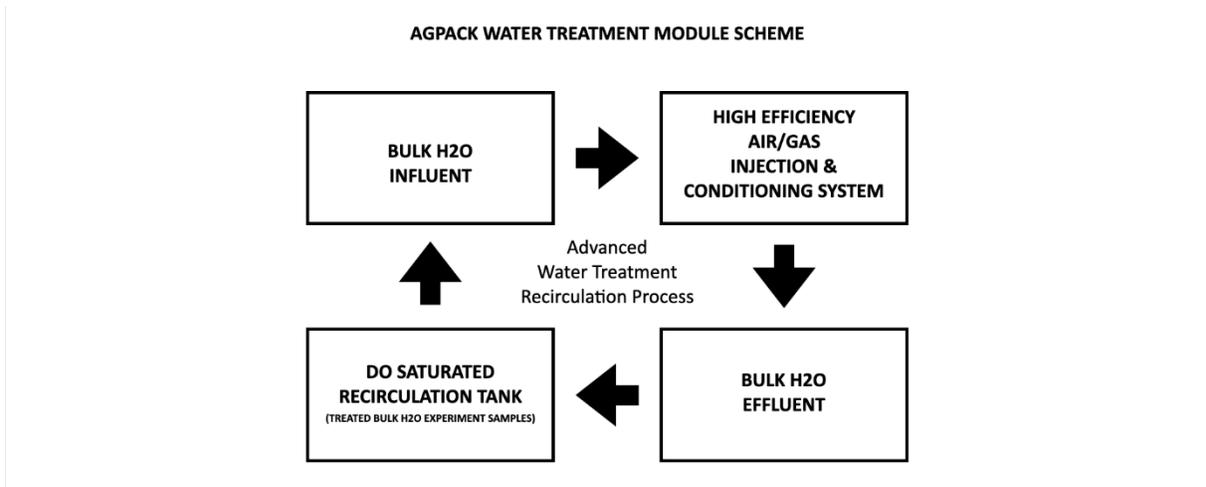


Figure 4: Recirculation time to reach 40ppm DO saturation (22c) was recorded at 12 minutes.

For both control/test sample groups, approximately 6 liters of un-treated/treated bulk water is transferred from reservoirs into the chiller for a single test. Both sample groups remained in the chiller at a pre-operating temperature of 25°C, as the working fluid, for the entirety of heat transfer experiment.

Procedures

The experiment was conducted using National Instruments' LabVIEW software package. The first step was to power on the chiller and allow for the temperature of the circulation fluid to stabilize to approximately 25°C (factory setting). This is done to ensure that there are little to no temperature variations in the collected data that are induced by a temperature change attributed to the chiller.

The next phase starts with increasing the voltage on the DC power supplies to begin powering the cartridge heaters. As the temperature of the working fluid begins to rise, we continue to raise the voltage on the power supplies. This process occurs over a sustained period in order to avoid subcooled boiling and potential burnout of the heaters.

As the working fluid approaches saturation temperature, we begin to record temperature data for the inlet and outlet of the condenser. The temperature at these two points is sampled once every three seconds. This process continues until the working fluid reaches saturation temperature and begins to vaporize. Data is recorded until the outlet temperature reaches a stable temperature at which point data recording is halted and the power supplies are shut down.

This concludes one cycle of the experiment. The same process is conducted for every circulation fluid tested for comparison.

In addition to the experiment in which the treated water was utilized as condensing fluid circulated through a coil via a recirculating chiller, a secondary experiment was conducted. This secondary experiment consisted of alternatively; utilizing the treated water as heating fluid, and observing the temperature response to a power input via the cartridge heaters. For this experiment, the power supplies were increased in a step manner at a rate of 30W every 3 minutes.

Results & Analysis

In our experiment we only consider the heat being removed by the copper coil condenser through the condensation of the steam being generated by the boiling of the working fluid. Thus, we can isolate the condenser coil as a single body to analyze.

Performing an energy balance on the condenser coil gives us

$$\Delta E = E_{in} - E_{out} + q_{gen} = 0 \quad (1)$$

where the total change in energy, ΔE , is equal to the difference between the energy entering the system, E_{in} , and the system leaving the system, E_{out} , plus, any energy generated, q_{gen} . Since energy must be conserved for all systems, we know that this net change must be equal to 0.

There is no energy being generated by the condenser and thus we can cancel out the q_{gen} term. Next, we know that any energy entering the system is in the form of heat. Thus, the E_{out} term will be rewritten as Q which has units of watts. We also know that the energy leaving the system is also in the form of heat, quantified by some temperature change of the circulation fluid. This term comes in a slightly more complex form which is $\dot{m}c_p\Delta T$ in which \dot{m} is the mass flow rate of circulation fluid through the condenser coil, c_p is the specific heat of the liquid, and ΔT is the temperature difference between the inlet and outlet of the condenser coil. We can then combine these terms to get

$$Q = \dot{m}c_p\Delta T. \quad (2)$$

This equation (2) is what we will use to quantify improvements to the overall heat transfer efficiency using KST treated water. That is, a higher Q indicates a larger amount of heat removed indicating that we are indeed increasing heat transfer efficiency by dissolving gases in water.

To quantify the significance of the preliminary lab results, we need to examine the amount of energy we are utilizing to treat the water and to thereby record an increase in efficiency. To do this we simply look at the average power consumed throughout the experiment. The rate of power consumption was recorded to be 2.7 KWH for a 38 GPM circulation rate of water and a total of 100 Gallons of total treated water. The time it took to reach 40ppm DO saturation recorded at 22°C was 12 minutes. To calculate the total amount of power that it took to generate the water used in the experiment we can use the following equation.

$$Q_{treat} = \frac{E}{t} \frac{\dot{m}_{exp}}{\dot{m}_{treat}} \quad (3)$$

This equation accounts for the excess flow rate of water that is not used in the experiment.

Now in order to quantify the energy savings resulting from this process we can simply subtract this Q_{treat} value from our original Q .

Discussion and future tests

Our preliminary bench test experiments show that dissolving gases in water indeed increases its specific heat transfer properties. For our experimentation we conducted tests using 2 types of gases for dissolving inside of working fluid. The first test conducted was a baseline experiment using plain tap water. The second and third tests conducted utilized dissolved oxygen and dissolved air in the treated water respectively. The results for these experiments can be found in Figure 5.

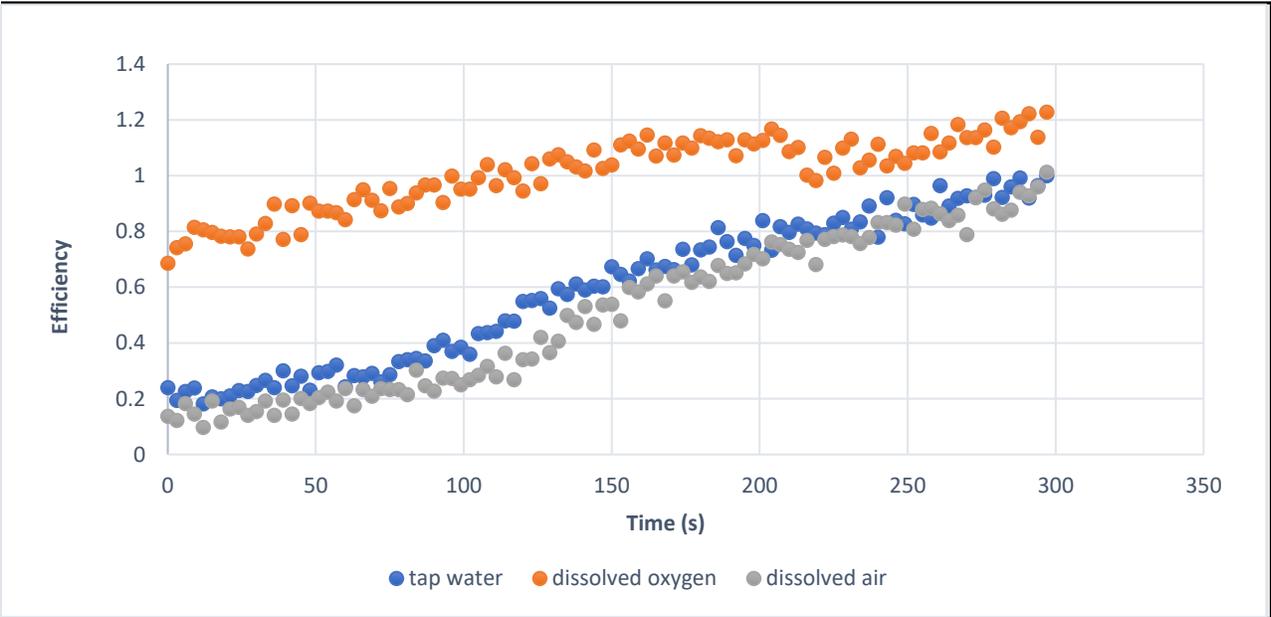
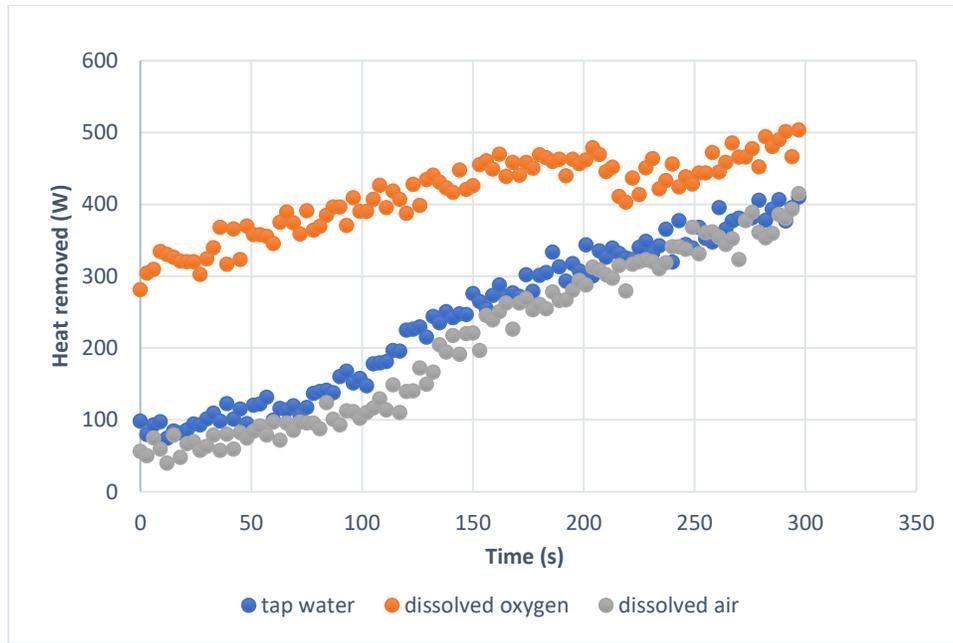


Fig. 5: A comparison of the amount of heat removed during the experiment normalized to the maximum amount of heat removed in the tap water experiment. Treated water using dissolved oxygen shows a significant increase of approximately 20% compared to the control tap water.



When the results from the treated water using dissolved oxygen are compared to those from the untreated tap water, we notice a significant increase in efficiency. Remarkably, there is a 20% increase in the amount of heat that is being removed through condensation. This result validates our hypothesis and the theories postulated by the Kairospace engineering team. Another interesting result is that there were no noticeable increases in the efficiency of the heat removal in the experiments using dissolved air in the treated water. This result, however, only remains true for the experiment in which the treated water was used as working fluid in the condenser.

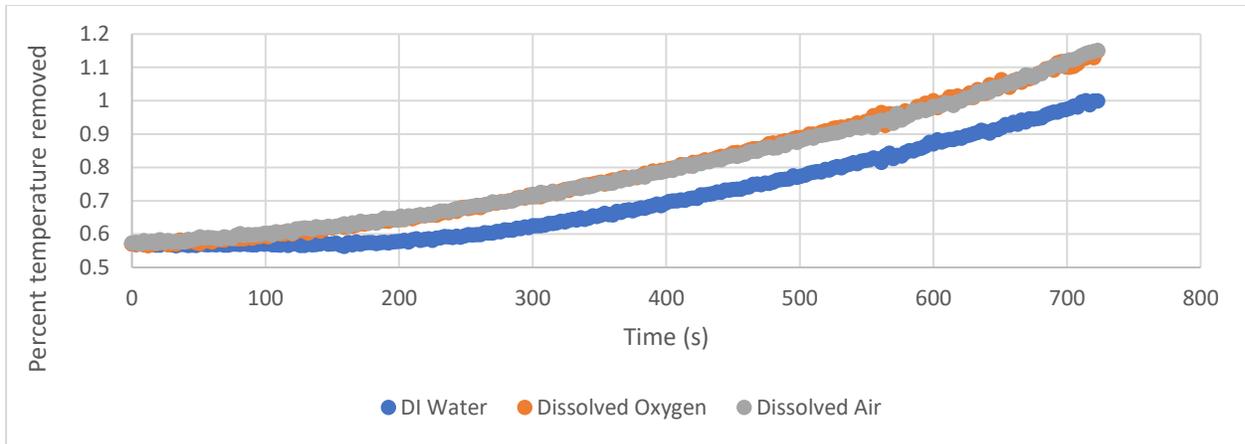


Fig. 6: A comparison of the amount of heat absorbed during the heating experiment. Values were determined by taking the temperature of the fluid in the experiment at each point and dividing by the maximum temperature of the untreated water (the final temperature measured). Once again, we see a significant increase in the amount of heat that is absorbed by the treated water in comparison to the untreated water.

When looking at the results for the heating experiment (the experiment in which the treated water was directly heated using the cartridge heaters), we once again observe improvement relative to the untreated tap water, this time however we also see an increase of approximately 15% in the amount of temperature that was absorbed via heating for **BOTH** the treated water samples (dissolved oxygen and dissolved air) relative to the untreated tap water. That is, the treated water is absorbing much more heat relative to the untreated water which once again confirms our hypothesis that dissolving gases into water increases thermal efficiency. This experiment validates that we can use the treated water in both heating and cooling scenarios and the properties remain the same.

Lastly, we can use our equation (3) to understand how efficient the process of treating the water is in terms of cost of energy to produce nanobubbles and the increased amount of energy that is removed using the treated water.

First, we can estimate the power cost for treating water with dissolved oxygen. Utilizing our recorded power usage of 2.73 kW-h and a processing time of 12 minutes combined with an estimate of both the flow rate used in the experiment (in the recirculation loop) and the flow rate produced by AG-PACK machine we can determine the net power cost.

$$Q_{treat} = \frac{9.83 * 10^6 \text{ W s}}{720 \text{ s}} \frac{0.047 \text{ kg/s}}{2.4 \text{ kg/s}} = 268 \text{ W}$$

Next, we can look at the power cost of treating water with dissolved air. This time we recorded a power usage of 2.06 kW-h and again a 12-minute processing time, the flow rates remained constant.

$$Q_{treat} = \frac{7.42 * 10^6 \text{ W s}}{720 \text{ s}} \frac{0.047 \text{ kg/s}}{2.4 \text{ kg/s}} = 201 \text{ W}$$

We have a one-time cost of 268 W to treat the water with dissolved oxygen and a one-time cost of 201 W to treat the water with dissolved air. Assuming that the water is used in operations in which there is no degradation (or minimal degradation) in the nanobubble content of the water, this cost will be easily offset by the amount of heat removed throughout the process in which the working fluid is used.

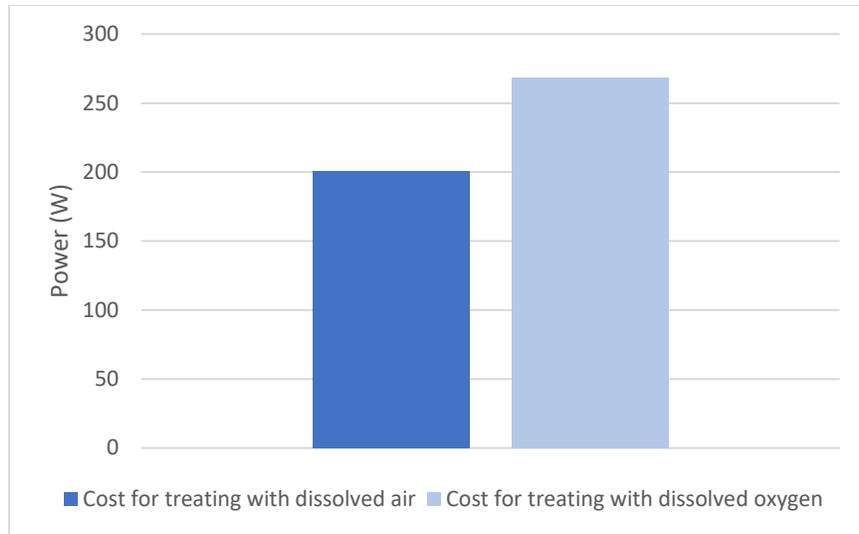


Figure 7: A comparison of the cost to produce treated water with either dissolved oxygen or dissolved air.

Although we have conclusively validated that treating water with dissolved gases increases thermal conductivity, it is recommended that further testing be conducted to build further statistical value and technical insight. Additional test groups should include the dissolution of various atmospheric gases produced with minimal energy consumption. A broader range of treated test groups will bring additional perspective and insights into underlying modes of action and applications. Different treatment configurations designed to increase power efficiencies and testing of various dissolved gases are of particular interest. This type of research opens the door to a variety of applications of advanced water treatment in real-world industrial settings. It is recommended that further testing be conducted at scale, such as in retrofitted HVAC cooling tower systems and other equipment and processes in which water is used to transfer or remove heat.

Specifically, we want to understand why air exhibits different results depending on the testing configuration. We also want to further explore how much degradation in the nanobubble content of the treated water exists in order to better quantify the cost effectiveness of treating water depending on the specific application in which it will be utilized.