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Small-Scale Solar Desalination Device for Drinking Water

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ABSTRACT

Water desalination is an energy-intensive process. The typical method of boiling water and passing it through membranes is not very efficient, especially at smaller scales. To remedy this a device was created that would both use less energy than traditional water desalination devices and also be energy efficient at a smaller scale. The main process that takes up a bulk amount of energy is the process of converting water from a liquid to a gas. I worked on a venturi tube that would use the principle of fluid mechanics to achieve a pressure drop in the tube sufficient enough that the water would naturally vaporize. By having airflow through this tube, we could inject water into the section where the pressure drop was achieved. The water would then undergo flash vaporization. This venturi tube would then be implemented into a larger device that would successfully filter salt out of water. With the completion of this device, it could be mass-produced and used in desert regions for single-family households that do not have easily accessible sources of fresh clean drinking water. By conducting computational fluid dynamics simulations and using previous research done on designing venturi tubes, we were able to design a tube that would sufficiently achieve the pressure drop required.

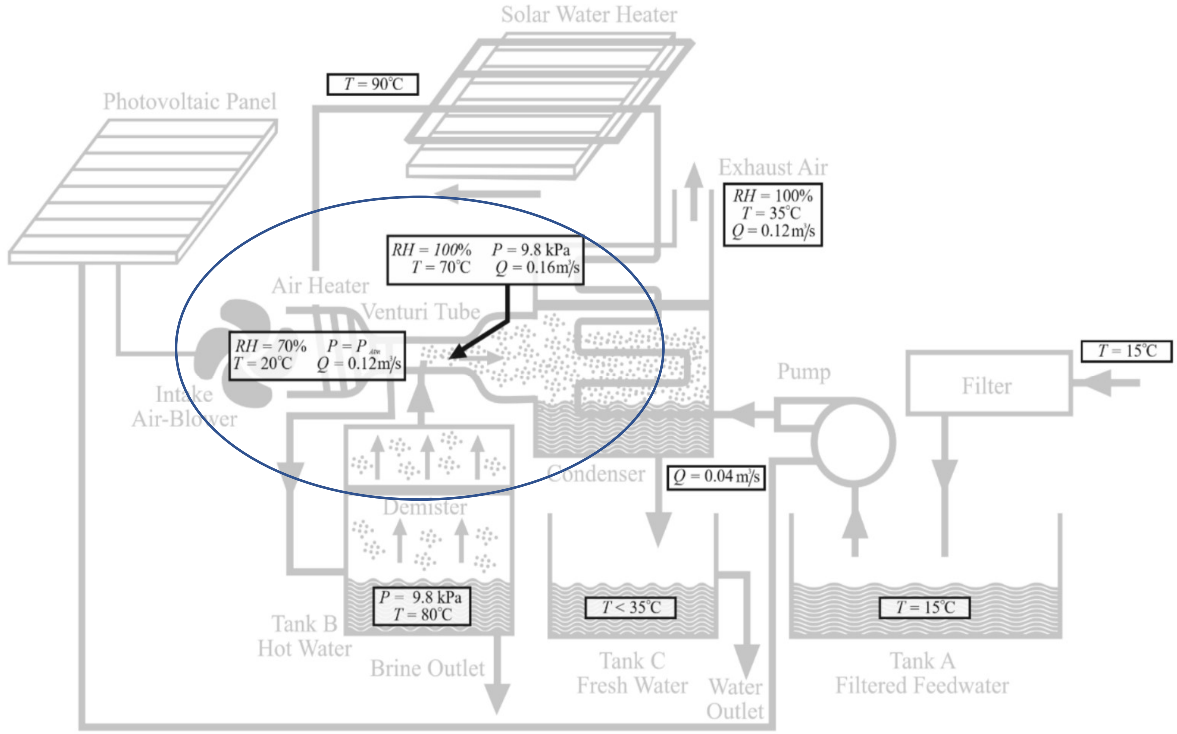
KEY TERMS

Solar ● Desalination ● Venturi Tube ● Computational Fluid Dynamics ●

INTRODUCTION

To achieve the flash vaporization of water, a sufficient pressure drop was needed. Initially, I calculated the minimum velocity at the section of the tube where the pressure drop would occur, also known as the throat or the constriction. It is derived by the following equation, $P_1 - P_2 = \frac{\rho}{2}({v_2}^2 - {v_1}^2)$. To derive the smallest throat velocity, v_2, I made the assumption that v_1 is very small in relation to v_2, essentially zero. It may also be noted that this calculation does not take into account the constraint that is put upon v_2, namely that it must follow the continuity equation $A_1 v_1 = A_2 v_2$. Without taking into account this relation the true velocity of v_2 would be even bigger. Doing the calculation, it was found that the velocity of the air at the throat must be a minimum of 789 $\frac{m}{s}$ to achieve a pressure drop from 101325 pascals to 9800 pascals. This specific amount was derived from the original calculations made for the desalination device as seen in figure 1. To reiterate, what should happen is that air should travel through the tube and speed up at the constriction where water would then be sprayed into the tube. This water would instantly vaporize and then be carried by the air through a mesh filter into a tank with a cooler temperature. It would then condense into liquid form and be ready for consumption.

(1)



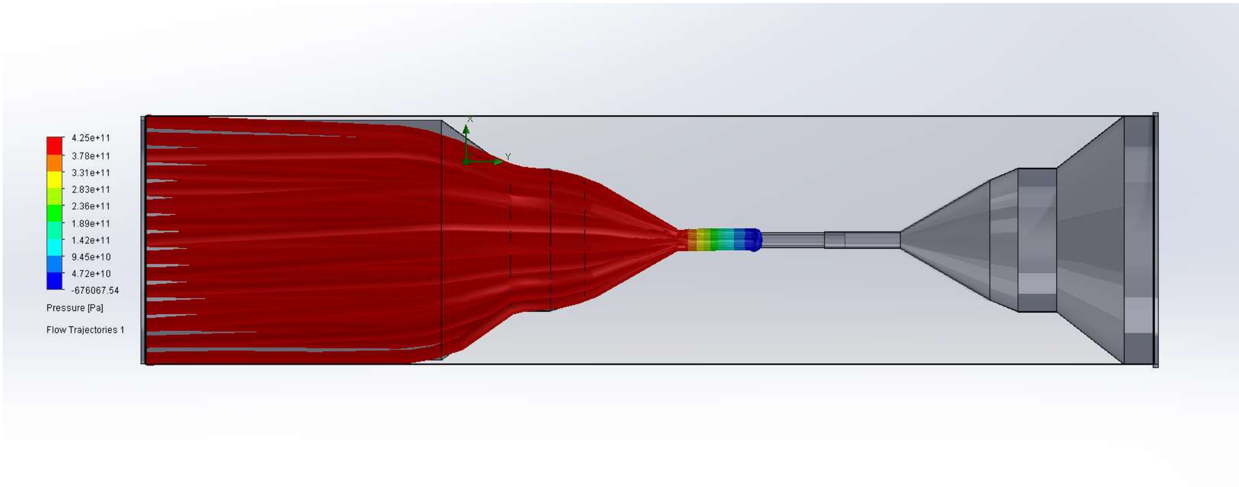
MATERIALS AND METHOD

The only material object that was used, was the venturi tube. The tube went through two designs, the initial design that I had no input on, and the redesign which I did to fix the various issues that the initial design had. The main method of conducting testing was through the SolidWorks software. Specifically, the flow simulation feature was used to conduct computational fluid dynamics (CFD) simulations on the tube to see if the desired outcome would be achieved given a certain flow through the tube. This was used in conjunction with calculations done by hand to verify the viability of using a venturi tube to achieve the desired outcome.

RESULTS AND FINDINGS

With the initial design, there were some errors that became apparent when conducting computer simulations on the tube. This was due to the fact that with the initial design and the pressure drop that was assigned to it, the minimum throat velocity was supersonic. This is not possible due to following different equation that governs compressible flow, $\frac{dV}{V} = -\frac{dA}{A}\frac{1}{(1-{M_a}^2)}$. When M_a is 1, $\frac{dV}{V} = \infty$. Having an acceleration of infinity isn't possible so this design for the venturi tube would not work out. The computer simulation software that was used, SolidWorks, outputted very bizarre values that didn't make the cause of this issue obvious, as shown in figure 2. Mainly, the pressure at the inlet was around 1 million times more than what it should have been. At first, I thought, that just doing a redesign of the tube would fix this issue in the simulation, not knowing that the true fault lay in the throat velocity. This redesign, shown in figure 3, while it did not fix the problem, it streamlined the design of the tube as it was based on ratios outlined by the British Standards Institution in figure 4. It also reduced the number of slopes the fluid had to collide with. It seemed that it would not be possible to use a venturi tube for vaporizing water as the pressure drop required would be too much, but it was found that if we heated up the water the pressure drop required decreased. Currently, the tube is now designed for a pressure drop of 30,000 pascals which would place the throat velocity at $223\frac{m}{s}$ which is well below supersonic. Since this satisfies the caveat of having subsonic flow at the throat, the tube will be 3d printed to a scaled-down model and tested later on to confirm its viability.

(2)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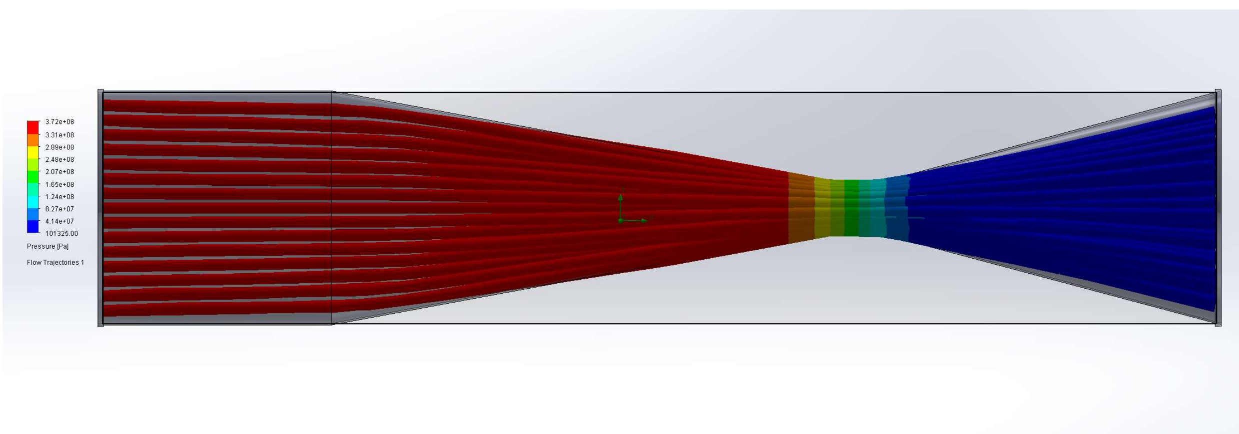
Pressure [Pa]
Flow Trajectories 1

(3)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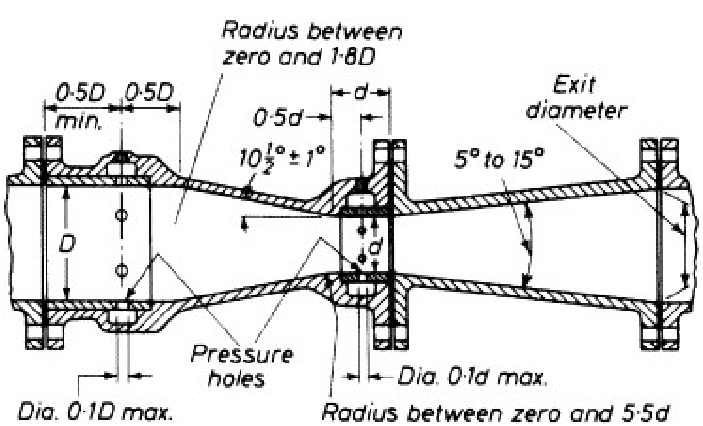
Flow Trajectories 1

(4)


Radius between zero and 1·8D
0·5D min.
0·5D
d
0·5d
10½° ± 1°
5° to 15°
Exit diameter
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Pressure holes
Dia. 0·1D max.
Dia. 0·1d max.
Radius between zero and 5·5d

DISCUSSION

It would have greatly expedited the design and testing process if it was brought up that the flow of fluids in venturi tubes are constrained to an upper limit of the speed of sound. As this wasn't known initially, the first design iterations were ultimately a waste as they were out of the realm of feasibility. However, the current design seems to work properly. The use of a venturi tube in this system should be much more energy efficient than traditional methods of desalination where the water must be boiled and passed through membranes. Boiling water alone is very energy intensive as it takes $2.26 * 10^6$ joules to boil 1 kg of water, while the tube simply has to heat up water from room temperature to 90 centigrade, which takes 292880 joules per 1 kg of water. With the tube, no added energy is required to vaporize the water. This project tested the use of a venturi tube on a small scale for single-family households. It will be interesting to see if this will be used in the future at a larger scale, perhaps replacing the current desalination plants that consume larger amounts of energy per kg of water filtered.

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