MARMARA UNIVERSITY
FACULTY OF ENGINEERING

HARVESTING WATER WITH A TRUNCATED CONE DESIGN BY USING AIR HUMIDITY

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HARVESTING WATER WITH A TRUNCATED CONE DESIGN BY USING AIR HUMIDITY

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ABSTRACT

Water is critical for every living being to survive. If there is not enough water, life of the creatures is endangered. There are several big reasons for the decrease in the amount of drinkable water on earth. The vast majority of these reasons are caused by humans. The terrestrial globe is overheated and continues to heat up due to the applications that increase the greenhouse gases used by humanity over the years. This phenomenon is briefly called global warming. The effects of global warming are manifested as climate changes today. Due to climate changes and global warming, fresh water reserves on terrestrial globe disappear day by day. Climate change is a fact that cannot be ignored. It is possible to say that one of the main reasons for decreasing in fresh water reserves is climate change. To overcome this problem, it is possible to produce water using Air Water Harvesting (AWH) technology. This technology transforms the high temperature and humidity in the environment into cold air and water with the help of electrical energy. The biggest advantage of this system is that it does not need any installation or heavy devices. Based on this advantage, the authors aimed to design a device that can be used in a simple and home environment. The reason why this design is planned in accordance with the home environment is that it is easy to manufacture and it is desired to be portable easily due to its size and weight.

Key Words : Humidity, Humidity Condensation, Heat Exchanger, Air Water Harvesting (AWH) Technology, Thermoelectric Cooler, Truncated Cone,

SYMBOLS

T	: Temperature
m	: Mass
v	: Inlet Velocity
ρ	: Density
A	: Area
$\dot{V}$	: Volume Flow Rate
$\dot{m}$	: Mass Flow Rate
C_p	: Specific Heat
h_f	: Enthalpy
$\dot{Q}$	: Heat Energy
W	: Relative Humidity Ratio
μ	: Dynamic Viscosity
Re	: Reynolds Number
R	: Top Radius
r	: Bottom Radius
h	: Height
L	: Length Of Outlet Pipe
V_{cone}	: Volume of Truncated Cone
Nu	: Nusselt Number
L_C	: Characteristic Length
h_{in}	: Heat Transfer Coefficient
k_{in}	: Thermal Conductivity
Pr	: Prandtl Number
α	: Thermal Diffusivity
ν	: Kinematic Viscosity

ABREVATIONS

AWH	: Air Water Harvesting
VCR	: Vapor Compression Refrigeration
LCA	: Lıfe Cycle Assessment
CFD	: Computational Fluid Dynamics
TFWG	: Thermoelectric Fresh Water Generator

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1. INTRODUCTION

One of the biggest problems on earth is climate change. Because of this phenomena capacity of fresh water sources decreases. Climate change is the biggest power behind the biggest problems facing the world today. As the effects of climate change gradually increase, drought, one of the biggest symptoms, is concentrated in certain parts of the world and causes water scarcity. D’Odorico et al. specifically identify desertification as the major problem lending momentum to climate change, expressing it as a “change in soil properties, vegetation or climate, which results in loss of ecosystem services like fresh water that are fundamental to sustaining life.” (D'Odorico et al. 2013, 326-344). If these existing problems persist, emerging threats may begin to increase and create major problems. [1].

Water, like oxygen, is one of the most important things for all living creatures to survive. [2]. Water is a dynamic liquid that has the ability to move. Therefore, it can cause flooding or drought in different areas. Lack of moisture in the air is the leading cause of the global water crisis [3]. Climate change, lifestyle change, economic and industrial changes have created more water needs, and the steady growth of economies has triggered water scarcity on earth. Water scarcity is that there is not enough water supplies to meet the water demand needed in a region and that area is not self-sufficient in terms of water. [4]. Water scarcity has become the biggest problem, affecting nearly two-thirds of the world's population. According to the world health organization, it is expected to affect about 2.8 billion people worldwide by 2025 [2]. Water scarcity can be experienced in two ways, they are physical and economical. Physical water scarcity is defined as insufficient water availability and economic water scarcity is defined as insufficient water treatment area and systems. While physical water scarcity is experienced in North African countries, many countries in Central Africa struggle with economic water scarcity. The main reason for this situation is low water distribution and very low efficiency of use. [4].

Only three percent of the world's fresh water is available for human consumption. Freshwater scarcity is perceived as a major threat facing the world. About 1.2 billion people for at least one month a year on all continents lack the access to fresh water [2]. According to most studies on water resources, it has been observed that water resources in the world have been decreasing every year. Almost half the world's population will face fresh water shortages in about 25 years [3]. The increasing water scarcity, due to ongoing desertification, salinization of fresh water sources and a still increasing global population poses a major challenge for society. Access to safe drinking water is so important that it has become a problem among the United Nations 'Millennium Development Goals'. Most approaches to producing new freshwater resources have been discovered [5]. For all that, atmospheric water, which is accepted as a renewable water reservoir to meet the world's water needs, does not attract enough attention.

One of the layers of air, the troposphere layer, contains water in the form of steam. Spreading to the earth at a height of 0-18 kilometers, this layer consists of a volume of water vapor between 0.01% and 4.25%. This means, on average, two percent of the air we breathe is water in the form of steam. When this average two percent water vapor volume of the troposphere layer is multiplied by 0.02, it is seen that the troposphere contains approximately 422 cubic kilometers of water vapor. [6].

Some arid areas have shortage of fresh water problem although there is high moisture in air. Especially in deserts where temperatures are really high and less rain. Even in deserts, which are very arid regions, the atmosphere contains a high amount of water. Atmospheric water in the atmosphere as water vapor and water droplets is equal to 10% of fresh water in lakes. This amazing amount of water can be collected for people to use effectively, directly or indirectly [6].

The atmosphere contains an estimated 12,800 trillion liters of renewable water. Atmospheric water harvesting (generation) has the potential to be a viable solution to meet global needs, especially where saltwater and brackish water is present [11]. Considering the difficulties and shortcomings of water supply and distribution systems, the idea of decentralized atmospheric water collection (AWH) systems has emerged in the past few years by several researchers. An AWH operates using vapor compression refrigeration (VCR) unit to condensate water from ambient air by cooling it below its dew point temperature [7].

The methods such as desalination and drawing water from the air are used to collect water. The water source is usually chosen based on availability and processing cost in that area. The collected water can be easily transmitted to the regions in need and the needs of the regions can be met by using renewable energy .There are two commonly used methods to extract water from atmospheric humid air using a renewable energy source: absorption-regeneration and dew point processes. The dew point technique is the process of cooling moist air to a temperature below dew point temperature using the solar cooling system. The absorption-regeneration process depends on the absorption of atmospheric air by the dehumidifier material [8].

Air Water Harvesting (AWH) technologies can be applied in humid and hot arid regions with low water scarcity. Atmospheric water source contains clean water which can be used even for drinking as well as agriculture and irrigation. Therefore, it is now a major promise in collecting water from the air, transportable water production by decentralized systems, providing water for community use in drought areas, and emergency water supply for post-disaster times [9].

AWH technologies do not require long pipe network work, as the air is a renewable resource, it can be used anywhere. The air intake can be done both naturally and by human-made designs. The advantages of air intake compared to other water sources are [2]:

- Compact and portable machinery that could be transported.
- Convenient for almost anywhere around the world where water is needed.
- No action for long and expensive delivery (pipe) systems.
- Supply of freshwater independently of existing water resources (sea, brackish, water).
- Limitless, free renewal of raw material (air) that contains enormous amounts of water.
- The process does not damage the environment in any way; no chemicals are involved and no wastes are formed.

The daily water collection capacity varies according to environmental conditions. By using energy sources such as solar energy, wind energy, fossil fuel, electricity etc. heat energy required for this technology can be provided. The required heat energy is obtained by using all kinds of energy sources, so the cost and energy deficiency can be tolerated. The AWH utilizes only 10 kW-h of electricity to harvesting 1,000 liters of water. In this technology, no chemicals are required, but some waste may occur. Air, which is a renewable energy source, is used at the entrance of technology.

Because of these reasons the ISO 14040 LIFE CYCLE ASSESSMENT (LCA) offered what AWH technology is environmental technology. For the system to work steadily, the humidity must be above a certain concentration, and the ambient air temperature must be a few degrees above the freezing temperature.

There are two methods for the AWH technology;

Desiccant method: In the desiccant method, a dryer is placed in a container and moisture is absorbed by this dryer. The relative humidity and temperature of the environment is tried to be kept constant. In this method, a fan draws air over the dryer. Desiccants are chemical substances that have a matchless property to absorb humid from atmosphere. Desiccants use 3 different methods to absorb moisture from the air: by physical absorption, forming chemical bonds or adsorption [10]. The water intake capacity of the dryers depends on some physical and chemical properties. Examples of dryers are calcium chloride, lithium chloride and water gel crystals.

Cooling condensation method: In cooling condensation types, a compressor passes the refrigerant through a condenser and then passes through an evaporator. This cooled air drops to the dew point and condenses and turns into water, and a fan pushes the filtered air over the coil.

The produced water is collected through a purification and filtering system and collected in a tank in order to get rid of viruses that can be transmitted from the environment. The relative humidity, ambient temperature and the size of the compressor determine the harvest of the water. As the relative humidity and air temperature rises, atmospheric water generators provide more effective operation. The cost depends on the size, how much efficiency is desired and what conditions will be challenged. [2].

The aim of this project is producing fresh and drinkable water using humidity in air. To be accomplished, authors have two different system designs which are containing either thermoelectric cooler or absorption chiller. Common characteristic of both systems is using solar energy to drive the system. Because this project has been decided to use in extreme warm surroundings with high humidity such as deserts. After water has been harvested by design has been chosen by cost and efficiency analysis, water needs to be analyzed if it’s drinkable. To achieve drinkability of harvested water, there might be mineralization needed. Therefore minerals contained by drinkable water needs to be researched and possible ways to achieve drinkability need to be found. Finally harvested water and minerals need to be mixed in a proper way.

In this study, a method that provides drinking water from air using thermoelectric effect has been tested. Goal of the authors is to have efficient results and use an original design to have a valuable contribution. A truncated cone designed in this direction. The model has been examined in different conditions depending on different parameters (inputs like velocity of the air, the temperature of the air, dimensions of the truncated cone such as top and bottom radius, height, inlet and outlet radius.). For this purpose, CFD analysis and simulation programs were utilized.

1.1. Literature Reviews

This type of water harvest is also a solution to many difficulties in water treatment systems. AWH will be a renewable and sustainable water resource since: i) atmospheric humidity is renewed naturally through evaporation from the ocean, and ii) AWH does not have any environmentally hazardous effects [7].

Lekouch et al. [12] focused on natural dew and fog collection from atmosphere in an arid region of southwest Morocco. They collected raw water using standard simple condensers. They also simulated the dew yield and reported potentials of 0.3–18.1 liter per m2 of collection surface from May to October (in total) for 15 Moroccan cities.

The thermal performance of a portable thermoelectric water cooling system was investigated in the study named "Performance of Portable Thermoelectric Water Cooling System" conducted by Ahmed Al-Rubaye, Khaled Al-Farhany and Kadhim Al-Chlaihawi at Iraqi El-Kadisiyah University. According to this study, it was possible to produce half a liter of water per hour [13].

A thermoelectric fresh water generator (TFWG) was developed based on the effect of thermoelectric cooling in the study "Experimental Investigations On A Portable Fresh Water Generator Using A Thermoelectric Cooler" conducted by Joshi, V., Joshi, V., Kothari, H., Mahajan, M., Chaudhari, M. and Sant, K. at the Vishwakarma Institute of Technology in India. It is possible to produce maximum 240 mL of water with the device developed according to this study. This study was published in November 2016 [14].

Niewenhuis and others aimed to design and create the prototype of an atmospheric water generator in 2012 with a top design project. They tried the liquid desiccant method for water harvesting and to make the resulting water drinkable. Wet desiccation is a process where a brine solution is exposed to humid air in order to absorb water vapor from that air. Then a regenerator's water vapor is removed from the solution. This method has become very popular as it can adapt to renewable energy, especially solar energy. In their paper (Niewenhuis et.al. 2012) and others have also described a novel and unique method to extract water from air. They discovered that it is possible to over compress moist air and condense itself. As pressure increases the dew point rises; thus, enough compression will force the dew point above the ambient temperature resulting in spontaneous condensation [15].

2. MATERIALS AND METHODS

This project aims to produce water with a truncated cone design. The truncated cone-shaped plate is planned to be produced in 3D printer for this water harvest. This work is done for high relative humidity and hot environments. It is aimed to circulate the air on a cold surface and intensify the moisture in it.

Thermo-electric cooler (Peltier) will be used. Peltier is chosen because the energy required for the operation of the Peltier is very low. This required energy can be obtained from renewable energy sources, especially from solar energy. Peltier is a thermoelectric cooler that usually operates at 12 volts. There are even more varieties such as 60w, 90w. When it is fed with 12 volts, it is needed to support a 60w Peltier with approximately 5 amps. When the Peltier is energized, it will be cold on one side and hot on the other. The more it is been cooled the heated side; it gets cooler the cold side. Therefore, when using Peltier, the heated side is cooled with the help of a fan. It will provide cooling faster by putting metal fins made of aluminum.

Figure 1. The work scheme of thermo-electric cooler (Peltier).

When Peltier is fed with direct current, it will work like a flow diagram on the side. This work is called the Peltier effect. Given all this, renewable energy sources are quite sufficient to operate this design system. Solar energy is the most suitable energy source for this design because this project will be realized in high temperature environments. Solar energy can be converted into electrical energy in a yield of 5% to 30% depending on the structure of the solar cell. In order to increase the power output, large number of solar cells are mounted on a surface by connecting them in parallel or in series, this structure is called solar cell module or photovoltaic module. In a well sunbathed area, one square meter solar panel produces an average of 250 watts of electrical energy. Since this system is predicted to operate with less energy than this, solar energy has been continued with consideration.

2.1. The Analysis and Simulation Layout and Procedures

There are many situations about the moisture carried by the air. There is graph below about moisture content of each temperature. In addition to that graph shows the quantities when the humidity %100 if humidity changes water in the air also change and it is generally decrease when humidity decrease there is direct proportion between them.

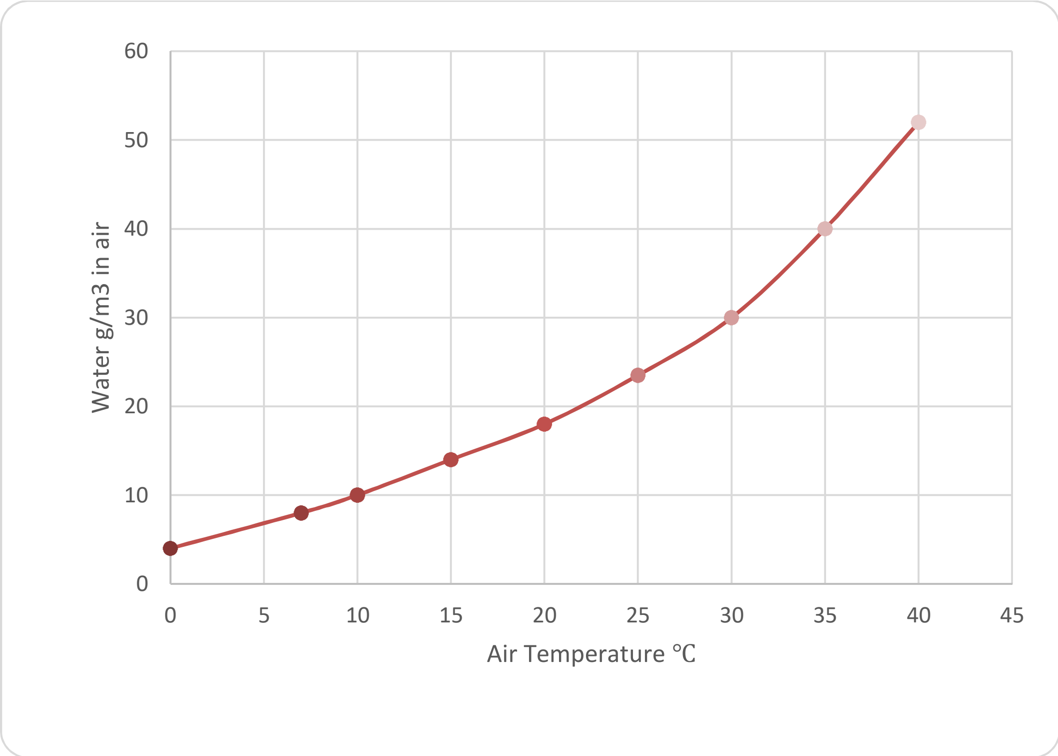


Figure 2. Saturation atmospheric moisture content at different temperatures [6].

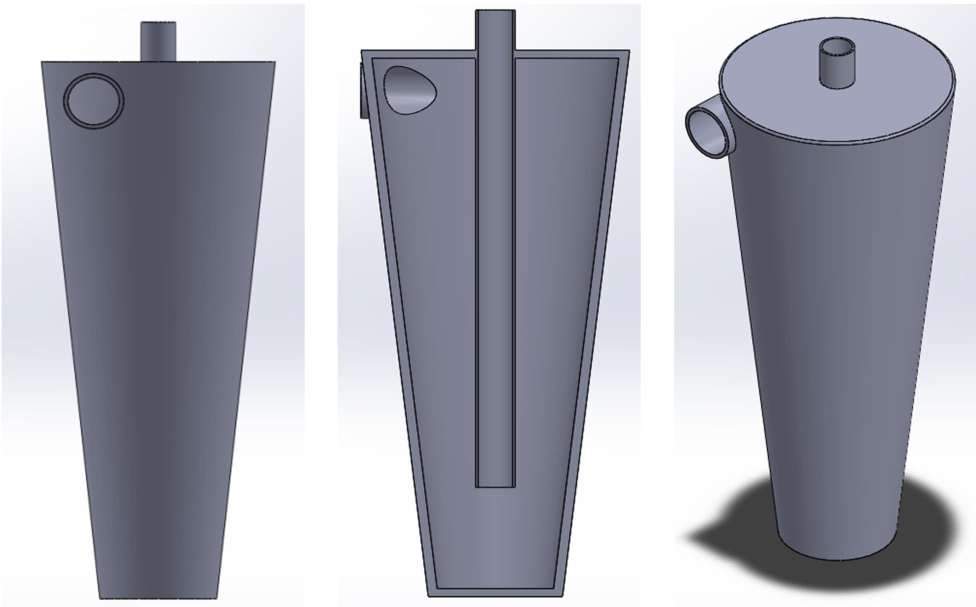


Figure 3. Right-side, section and isometric views of the design.

This truncated cone shaped design will be tested under some initial conditions for the purpose of water production, and analysis will be done and appropriate design parameters will be revealed.

There are lots of places on earth which have more than 60% humidity such as: Antalya, Alaska, Arizona, California, Bangkok, Las Vegas, Hon Kong, Mexicali, Melbourne, Kuala Lumpur, Phoenix, Athens, Cairo, Florida, Georgia etc. Based on these data, the first boundary condition was determined as 60% humidity. Some of these places are eliminated given the second boundary condition which is 35°C ambient temperature. While doing the analysis, the authors defined the inner surfaces of the object as cold surfaces. It was decided to cool these cold surfaces with the help of thermoelectric coolers. While doing the analyses, it was decided to identify the cold surfaces mentioned before as 10°C. The main reason for choosing 10°C is that the production can take place and the cooling capacity of thermoelectric cooler is limited.

In the first analysis part of the project, realistic dimensions were estimated and a design was revealed. Dimensions of this design are mentioned in "CFD Analysis" part by the authors. In this design, it is aimed to observe the amount of water produced when the initial temperature and humidity rate is kept constant and the inlet velocity changes. It was aimed to find an optimum velocity value here because it is known that getting more air inside did not always mean more water harvest.

Another part of the analysis and simulations was related to the dimensional properties of the truncated cone shape. Which means, dimensional increase or decrease in certain parts of the truncated cone shape would make changes in results. While some of it is being changed, others should be fixed and analysis and graphics should be created. As a result of these graphics, necessary comments can be made easily and the operation of geometry can be understood.

The simulation and analysis of the project that will actually work will be fixed volume analysis. For final this analysis, a 10 liters volume truncated cone will be considered because device is planned to use at home environment. The upper diameter and height ratio will be changed in this fixed volume. Furthermore the upper diameter and the lower ratio will be changed. After observing the results of these changes, optimum diameter and height ratios for fixed volume will be revealed and the best possible form of the design will be obtained.

The final analysis and simulations of the temperature analysis on the best possible form of the design is made. First, capacity of producing water will be examined by changing the inlet temperature. Afterwards, water temperature will be analyzed by changing the wall temperature of the truncated cone.

After all these analysis steps, the necessary things have been learned and it will be studied to calculate the heat energy needed back and how many Peltiers will be provided this heat energy, how to adapt these pelts to the shape. In addition to all these, authors decided to write an algorithm to observe daily production with real weather forecast data. Simple thermodynamic laws will be used for calculations and help will be provided from psychometric chart. The results will be revealed by calculating the amount of water carried by the moist air and how much of it left on the system.

2.2. Theoretical Background and Calculations of Production

Water harvesting from atmospheric air is accomplished using cooling with the dehumidification process. In this process, the relatively warmer air with certain relative humidity is exposed to a surface with colder temperatures. As the warm air cools down, its temperature drops and its relative humidity increases. When warm humid air gets in contact with a cold surface, its temperature drops to the dew point temperature and some of the water vapor in air condenses. Using psychometric chart, the properties of air during heating, cooling, humidification and dehumidification processes can be determined [16].

The first initial condition is 35 ^{o}C 60% relative humidity when looking at the psychometric chart above, the humid ratio of air is 21.530 g/kg at 35 ^{o}C 60% relative humidity. Furthermore the humid ratio of air is 14.185 g/kg at 19.38 ^{o}C 100% relative humidity. The humid ratio difference between this inlet and outlet will be used to calculate the water we harvest. There is also energy consumption calculation of the system. In this values design harvest 7.345 g/kg water which mean is when design take a kilogram air it harvest 7.345 gram water.

$\rho = 1.146$ kg/m^3

$v = 0.6$ m/s

$$A = \pi \times r_{inlet}^2 \quad (1)$$

$A = 3.14 \times 0.03^2 = 2.826 \times 10^{-3}$ m^2

$$\mu = 1.895\ x\ 10^{-5}\ \frac{kg}{m\ x\ s}$$

$$\dot{V} = v \times A \quad (2)$$

$\dot{V} = 0.6 \times 2.826 \times 10^{-3} = 1.696 \times 10^{-3}\ m^3/s$

$$\dot{m}_{air} = \rho \times \dot{V} \quad (3)$$

$\dot{m}_{air} = 1.146 \times 1.696 \times 10^{-3} = 1.942 \times 10^{-3}$ kg/s

$$Re = \frac{\rho\ x\ v\ x\ (2\ x\ r_{inlet})}{\mu} \quad (4)$$

$$Re = \frac{1.146\ x\ 0.6\ x\ 0.03\ x\ 2}{1.895\ x\ 10^{-5}} = 2177$$

Reynolds number (Re) is determined by the velocity of the fluid, its viscosity, the diameter of the pipe carrying the fluid, and the density of the fluid. The reason for this calculation is to determine the type of flow. There are three types of streams. The first is laminar flow, the second is transient flow and the last is turbulent flow. According to calculation with equation (4), flow is assumed as laminar, because Reynolds number is found smaller than 2300. Further calculations are made based on this assumption. Mass flow rate at inlet is 1.942×10^{-3} kg air per second. This means everyday 167.816 kg air is processing. After that how much water is produced by using the difference of humidity ratio at inlet and outlet can be calculated as 1.233 L/day.

$$\dot{m}_{total} = \dot{m}_{water} + \dot{m}_{air} \quad (5)$$

$$\dot{m}_{air} h_1 = \dot{m}_{air} h_3 + \dot{Q}_{cooling} + \dot{m}_{water} h_{water}$$

$$\dot{Q}_{cooling} = \dot{m}_{air}(h_1 - h_3) - \dot{m}_{water} h_{water} \quad (6)$$

After thermodynamic manipulations on equation (6), equation (7) is obtained.

$$\dot{Q}_{cooling} = \dot{m}_{air}\ x\ C_p\ x\ (T_1 - T_3) - \dot{m}_{air}\ x\ (\omega_1 - \omega_3)\ x\ h_{f\ at\ T_3} \quad (7)$$

$$\dot{Q}_{cooling} = 1.942\ x\ 10^{-3}\ x\ 4.182\ x\ (35 - 19.38) - 1.942\ x\ 10^{-3}\ x\ (2.153\ x\ 10^{-2} - 1.42\ x\ 10^{-2}\ )\ x\ 83.915$$

$$\dot{Q}_{cooling} = 0.1257 \text{ kJ/s}$$

$$\dot{Q}_{cooling} = 0.1257 \text{ kJ/s} = 0.1257 \text{ kW} = 125.7 \text{ W.}$$

$$\frac{\dot{Q}_{cooling}}{\dot{m}_{air}} = \frac{0.1257\ kJ/s}{1.942\ x\ 10^{-3} kg/s} = 64.72 \text{ kJ/kg}$$

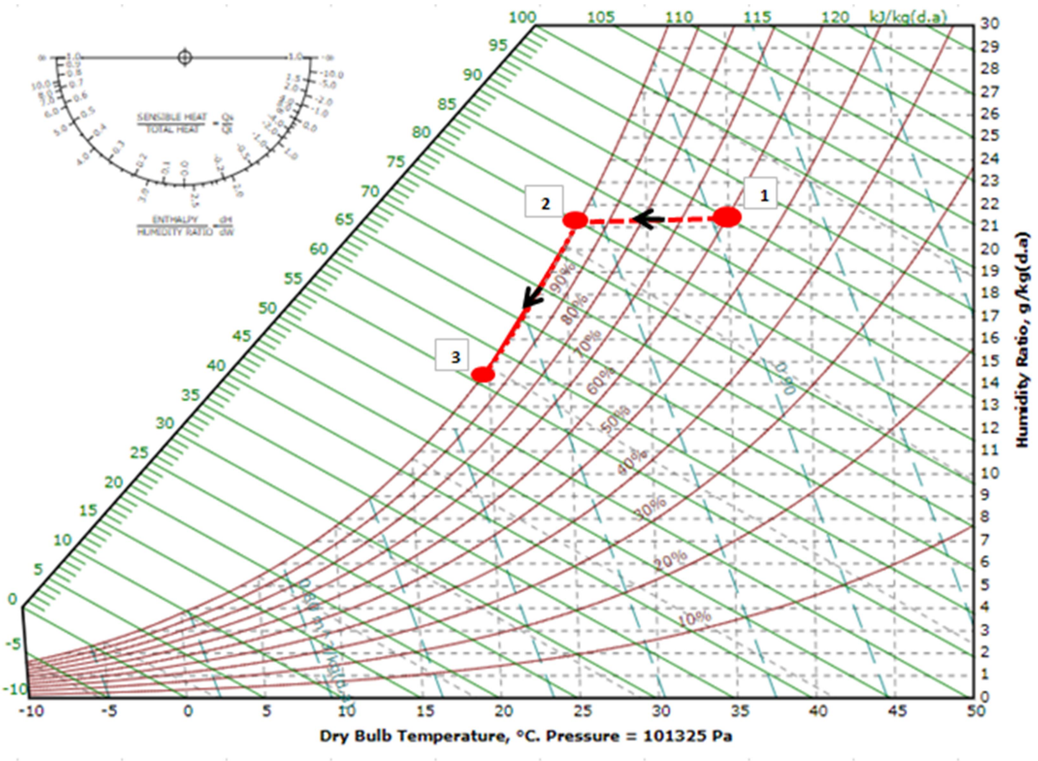


Figure 4. The locations of all changes on psychometric chart.

According to boundary conditions, 35°C and 60% relative humidity, point (1) is found on psychometric chart. Point (2) is obtained by cooling down air at constant humidity ratio till air reaches 100% relative humidity. After air reaches 100% relative humidity it starts to loose humidity ratio until it reaches outlet temperature where point (3) is obtained.

2.3. Theoretical Background and Calculations of Volume of Object

$$V_{cone} = \frac{\pi}{3}\ x\ (R^2 - r^2)\ x\ h \tag{8}$$

Calculation of R and r values when R/r changing at 10 liters constant volume and 0.5 meters constant height using equation (8).

$V_{cone} = 10\ L = 0.01\ m^3$

h = 0.5 m

R/r = 2, R= 2x and r =x

$0.01 = \frac{\pi}{3}\ x\ ((2x)^2 - x^2)\ x\ 0.5$

x = 7.98×10^{-2} m

Therefore R and r values calculated as $15.96\times 10^{-2}\ m$ and $7.98\times 10^{-2}\ m$ respectively.

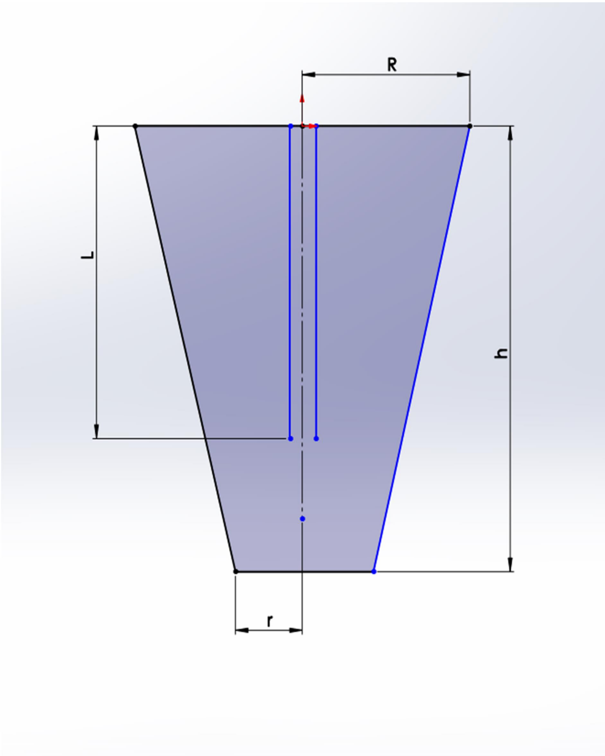


Figure 5. The symbols and their locations for constant volume analysis.

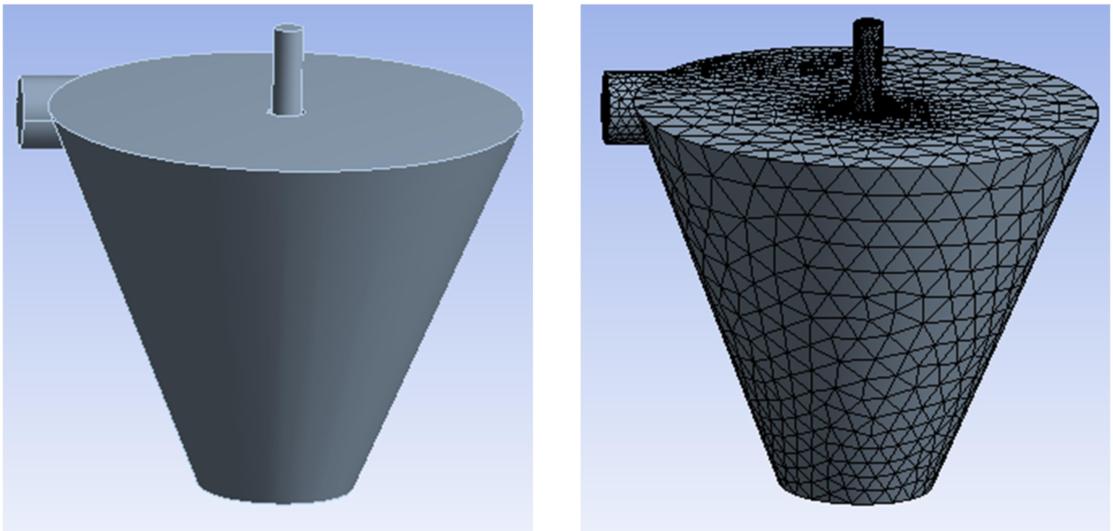
It was planned to make analyses by changing the proportions of the dimensions relative to each other in *Figure 5*. Equation (8) is used for all constant volume analysis and dimensions are found.

3. CFD ANALYSES AND RESULTS

3.1. Preliminary Analysis

Firstly, the measurements given were decided by the authors since there was no study made with the truncated cone and dimensions for it. While determining these dimensions, the authors decided that the size of the object should not be too large to be used in the home environment. Dimensions of first design;

Top radius	: 0.15 m,
Bottom radius	: 0.05 m,
Height	: 0.5 m,
Inlet radius	: 0.045 m,
Outlet radius	: 1.75×10^{-2} m.



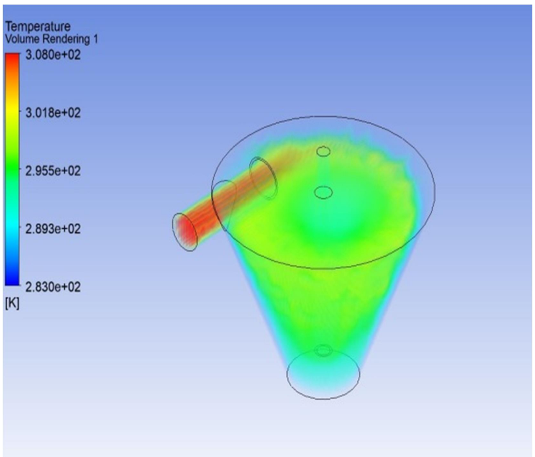
(a) **(b)**

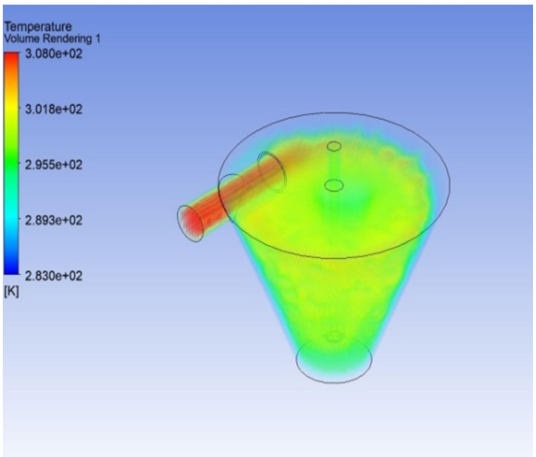
Figure 6. (a) First design before mesh generation, **(b)** First design with mesh generated.

Based on the dimensions given above, the solid model drawn in the "SOLIDWORKS" program and the generated mesh in the "ANSYS Fluent" program are seen above. While doing this, mesh was generated without changing the default settings of the program. After the first analysis, it was observed that water production took place. However, in order to bring this production to optimum levels, it was decided to re-analyze by changing the inlet velocity and dimensions.

3.2. Inlet Velocity Variation

The importance of finding the optimal inlet velocity for increasing water production was investigated. The inlet velocity is important because it directly changes the mass flow rate at the inlet. After the mass flow rate exceeds the optimal level, water production decreases, and after exceeding a certain limit, water production stops completely. The main reason for this is that the cooling capacity of the closed volume is constant and if this capacity is exceeded, the air cannot be cooled sufficiently.





(a) **(b)**

(a) 0.3 m/s, **(b)** 0.6 m/s

Figure 7. The optimum velocity analysis for different values.

Based on the volume of the object, the wall temperature of 10 degrees and previous experiences, it was decided to start this analysis with an entry speed of 0.3 m/s and continue with increasing intervals of 0.1m/s. These analyses continued until it was observed that water production reached decreased after it reached its maximum level. During the analysis the inlet temperature and the wall temperature were taken as constant and the outlet temperature was obtained with the help of the program. The corresponding humidity ratio (w) of the outlet temperature and 100% relative humidity on psychrometric chart was obtained.

Table 1. The results of the harvested water of first design with different velocities.

Velocity (m/s)	Exit temperature (°C)	Amount of Water (Liter/day)
0.3	19.152	1.44
0.4	20.422	1.63
0.5	21.767	1.61
0.6	22.993	1.42

As shown in *Table 1* it was observed that as the inlet velocity increased, the outlet temperature also increased. The reason for this is the increase in mass flow rate, as mentioned earlier.

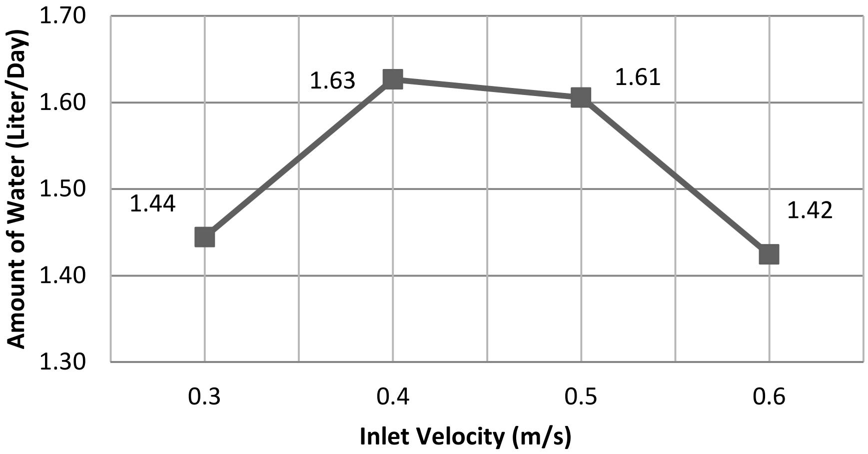


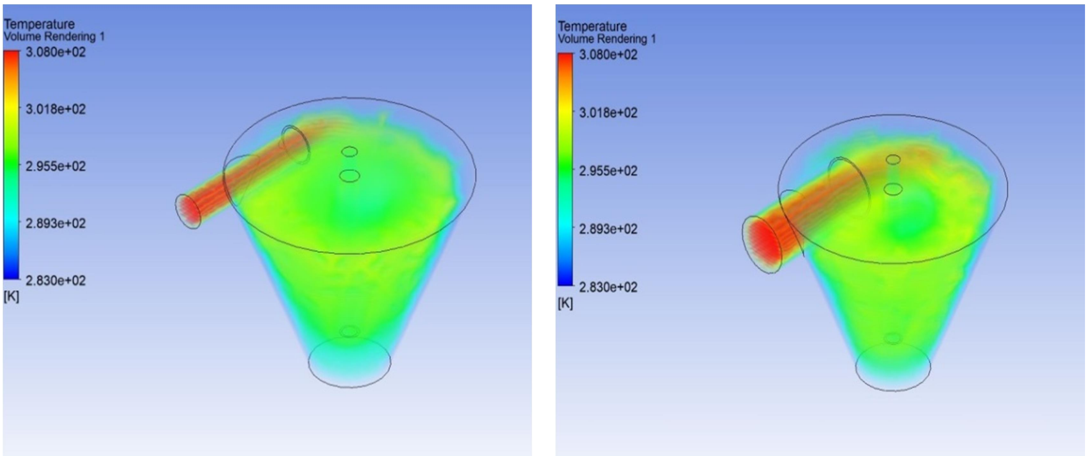
Figure 8. The graph of the harvested water with different velocities.

As shown on *Figure 8*, the amount of water production corresponding to each velocity changes. According to these results, the highest production is provided with an inlet velocity of 0.4 m/s. The optimum speed for this object is therefore chosen as 0.4 m/s. The optimum inlet velocity is different for each object. For this reason, this method was continued by the authors in all analyzes and the optimum velocity was determined for each object.

3.3. Inlet and Outlet Radius Variation

It was decided to make changes on the design in order to increase the amount of water production. As it is known that water production will increase with increasing the volume of the object, the connection between the dimension change of the inlet and outlet radius and the amount of production was observed in order to perform an optimization study without volume change. Same dimensions have been used in the inlet velocity variation except for inlet and outlet radius.

3.3.1 Inlet Radius Variation



(a) **(b)**

Figure 9. The analysis with **(a)** 0.04m and **(b)** 0.07m inlet radius.

As in the inlet velocity analysis, changing the inlet radius has a direct effect on the mass flow rate. When the temperature analysis in *Figure 9* was examined, the effects of the inlet radius change were observed as the change of the outlet temperature.

Table 2. The harvested water value for different inlet radius with same design.

Inlet Radius (m)	Optimal Velocity (m/s)	Amount of Water (L/day)
0.04	0.50	1.73
0.05	0.35	1.62
0.06	0.20	1.40
0.07	0.15	1.26

During the inlet radius change analysis, a separate inlet velocity optimization was made for each inlet radius value as mentioned before. It was observed that the optimum velocity required for maximum production decreases as the radius increases.

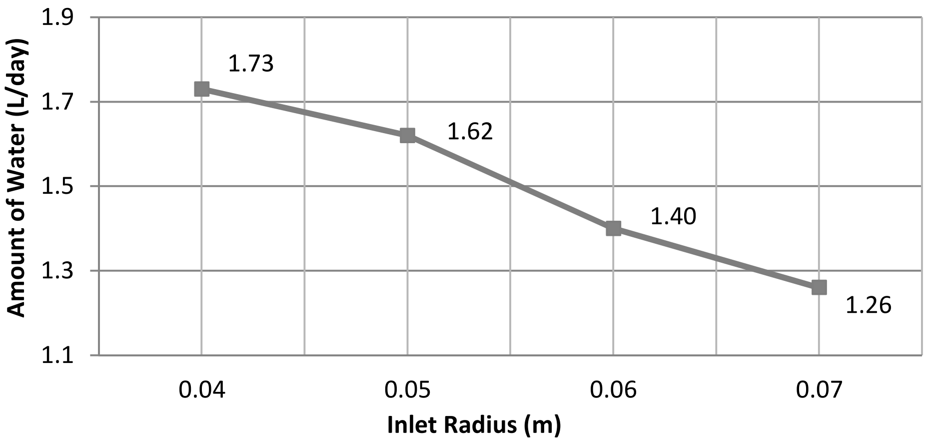
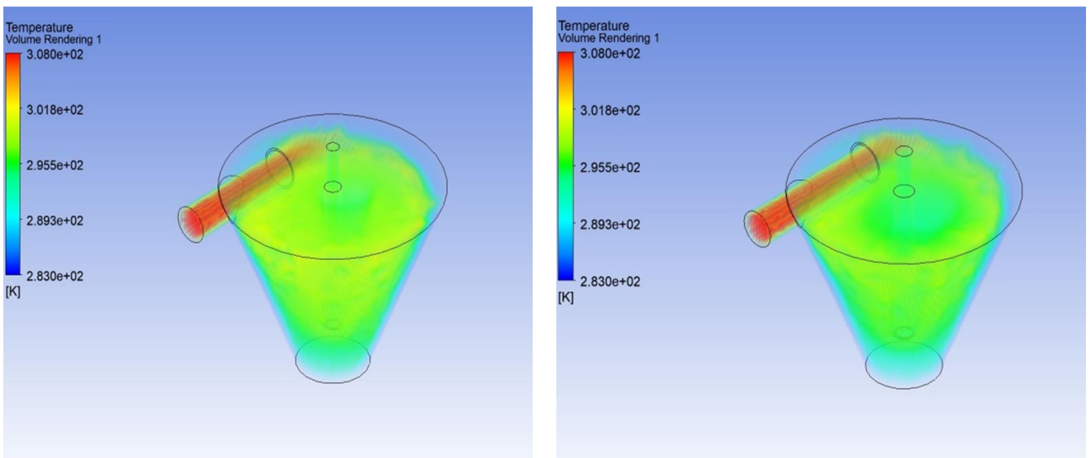


Figure 10. The graph of harvested water with different inlet radius.

As shown in *Table 2 and Figure 10*, with the increases of inlet radius production amount decreases. Since geometry of inner volume is not changing, with the increase of inlet radius production decreases due to large amount of mass flow rate. Therefore, temperature and humidity ratio of air at outlet decreases and caused less production.

3.3.2 Outlet Radius Variation



(a) **(b)**

Figure 11. The analysis with **(a)** 1.65×10^{-2}m and **(b)** 2.05×10^{-2}m outlet radius.

Changing the outlet radius did not make any difference in mass flow rate as predicted. As seen in *Figure 11*, no major differences were observed between the outlet temperatures.

Table 3. The harvested water value for different outlet radius with same design.

Outlet Radius (m)	Optimal Velocity (m/s)	Amount of Water (L/day)
1.65×10^{-2}	0.40	1.65
1.85×10^{-2}	0.40	1.64
1.95×10^{-2}	0.40	1.61
2.05×10^{-2}	0.40	1.71

The optimum inlet velocity analysis was not performed at this step, since the change of the outlet radius did not change the initial conditions. Optimum inlet velocity is accepted as 0.4 m/s according to previous inlet velocity analysis.

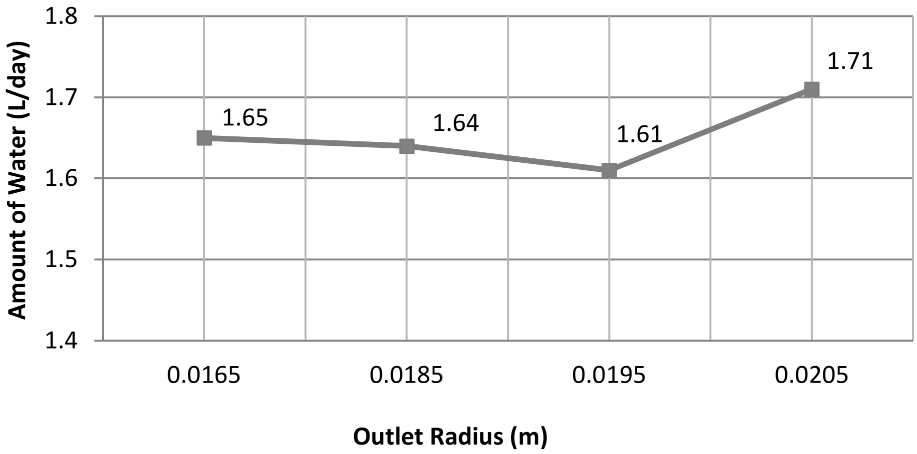


Figure 12. The graph of harvested water with different outlet radius.

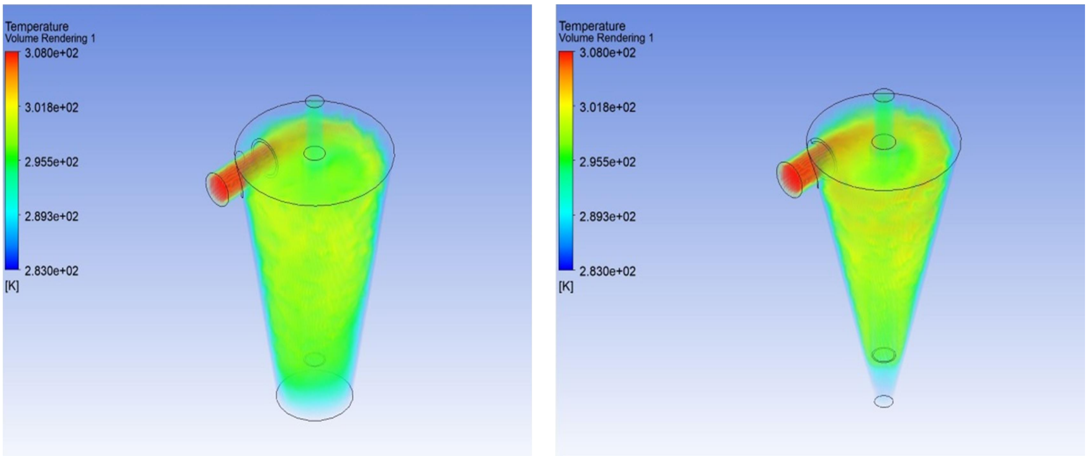
As seen in *Table 3 and Figure 12*, the increase in the outlet radius did not have a significant effect, increase or decrease, in water production. The change of the outlet radius only changes the speed of the air leaving the object. An average value was chosen by the authors since the high or low output speed has no effect on water production and only effects the external environment.

3.4. Dimensions Variation with Constant Volume

Analysis and manufacturing problems were evaluated and it was decided by the authors to choose 10 liters volume for the main design geometry truncated cone.

3.4.1 Ratio Effect between Top Radius and Bottom Radius

This analysis was made by changing the R/r value from 2 to 6. The reason for this value to change between 2 and 6 is to prevent the truncated cone from being too wide or too narrow.



(a) **(b)**

(a) R/r = 2 and **(b)** R/r = 6

Figure 13. The analysis of the changing R/r ratio when volume is constant.

As seen in the *Figure 13*, as the ratio increases, a contraction and shortening observed in the object. The increase in this rate caused the outlet temperature to increase.

Table 4. The harvested water when R/r ratio changes.

R/r	Height (m)	Bottom Radius (m)	Top Radius (m)	Water (L/day)
2	0.50	7.98×10^{-2}	0.160	1.321
3	0.50	4.89×10^{-2}	0.147	1.208
4	0.50	3.57×10^{-2}	0.143	1.154
5	0.50	2.82×10^{-2}	0.141	1.106
6	0.50	2.34×10^{-2}	0.140	1.131

The *Table 4* shows the change in the water production by changing the R/r ratio in constant volume. In this study volume and height have been kept constant and top and bottom diameters are calculated with the help of “Matlab”.

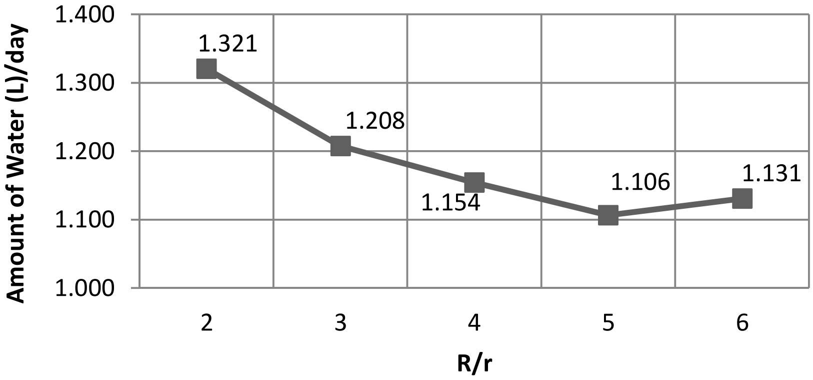
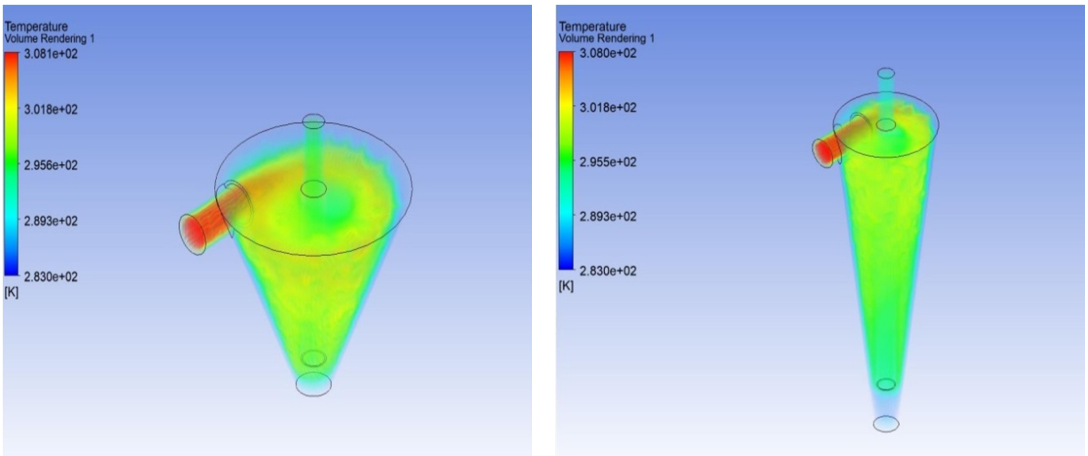


Figure 14. The graph of harvested water when R/r ratio change at constant volume.

It is been observed that when R/r ratio increases, production decreases. Therefore it’s been decided to use R/r ratio as 2. It is not allowable to take ratio less than 2 because productivity decreases too much.

3.4.2 Ratio Effect between Height and Top Radius

This analysis was made by changing the h/R value from 2 to 6. The reason for this value to change between 2 and 6 is to prevent the truncated cone from being too short or too long.



(a) **(b)**

(a) h/R = 2 and **(b)** h/R = 6

Figure 15. The analysis of the changing h/R ratio when volume is constant.

As seen in the *Figure 15*, as the ratio increases, a contraction and elongation observed in the object. The increase in this rate caused the outlet temperature to decrease.

Table 5. The harvested water when h/R ratio changes.

h/R	Height (m)	Bottom Radius (m)	Top Radius (m)	Water (L/day)
2	0.342	0.035	0.171	0.883
3	0.450	0.035	0.150	0.803
4	0.547	0.035	0.137	1.162
5	0.637	0.035	0.127	1.376
6	0.722	0.035	0.120	1.472

The *Table 5* shows the change in the water production by changing the h/R ratio in constant volume. In this study volume and bottom diameter have been kept constant and top diameter and height are calculated with the help of "Matlab".

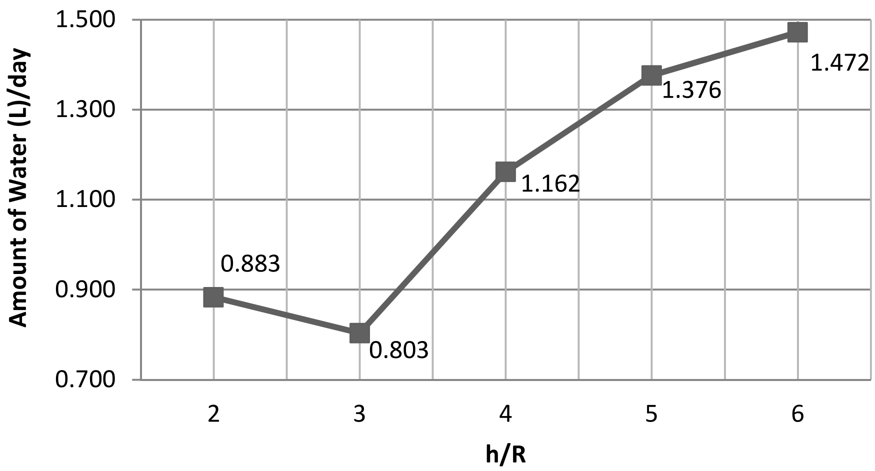
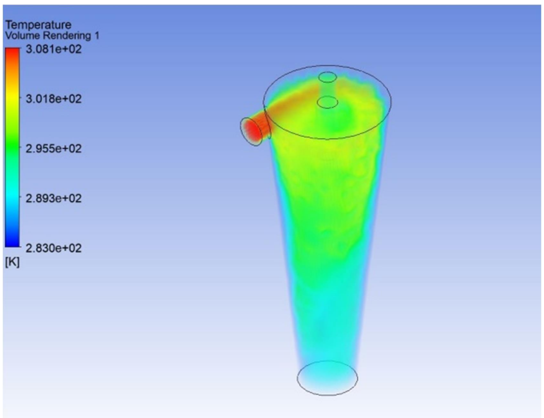


Figure 16. The graph of harvested water when ratio h/R change at constant volume.

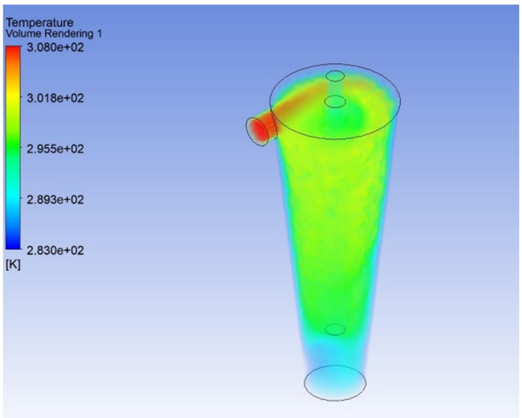
It has been observed that when h/R ratio increases, production increases. However if h/R ratio is selected as 6, top diameter would be too small. Therefore it has been decided to use h/R ratio as 5 because the productivity is considered.

3.4.3 Ratio Effect between Height and Length of the Outlet Pipe

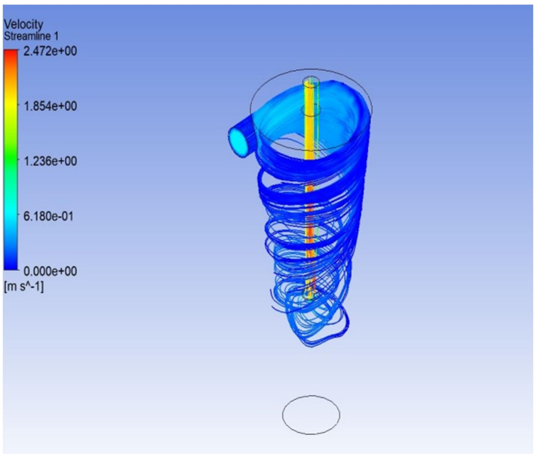
The aim of this study was to observe whether the length of the outlet pipe has an effect on outlet temperature. This analysis was made by changing the L/h value from 0.2 to 0.8. The dimensions decided to be used in this study were calculated by analyzing the data obtained from previous analyzes. Therefore it’s been decided to use R/r ratio as 2 and h/R ratio as 5 and exact dimensions are calculated with the help of “matlab”.



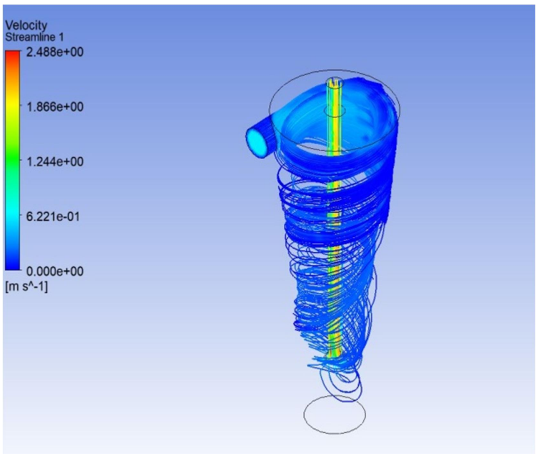
(a)



(b)



(c)



(d)

(a) and (c) L/h = 0.2 and **(b) and (d)** L/h = 0.8

Figure 17. The analysis of the changing h_0/h ratio when volume is constant.

As seen in *Figure 17*, as the length of the outlet pipe increases, the air inside the object interacts bigger surfaces. Therefore longer outlet pipe ensures the temperature of the exiting air is to be lower.

Table 6. The harvested water when L/h ratio changes.

L / h	Height (m)	Bottom Radius (m)	Top Radius (m)	Water (L/day)
0.2	0.680	0.068	0.136	0.925
0.4	0.680	0.068	0.136	1.057
0.6	0.680	0.068	0.136	1.165
0.8	0.680	0.068	0.136	1.250

As seen in the *Table 6*, increasing the length of the outlet pipe increased production because the air interacted with larger cold surfaces inside.

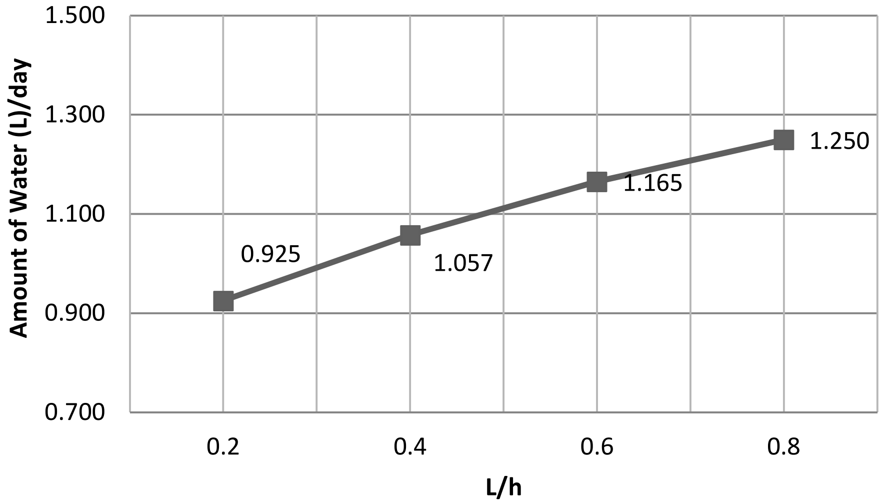
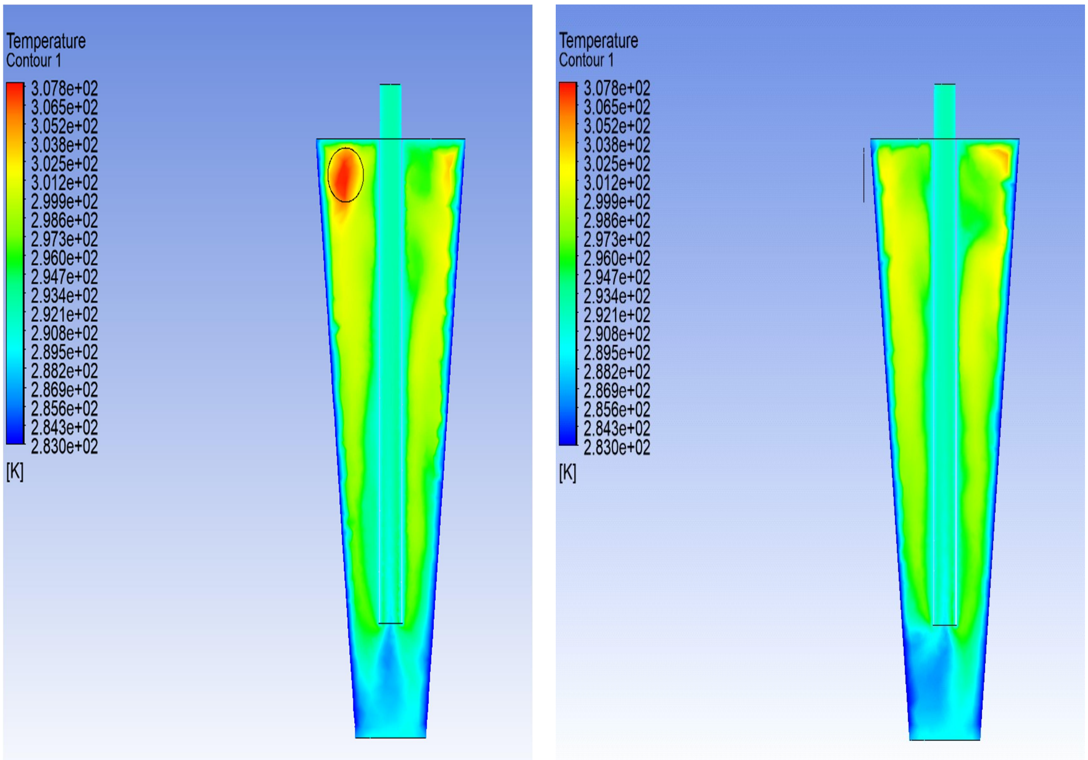


Figure 18. The graph of harvested water when L/h ratio change at constant volume.

With the increase of the pipe length, water production increases proportionally. But the maximum L/h ratio can be chosen is 0.8. If this ratio is more than 0.8, it causes clogging of the connection between the outlet pipe and the internal volume of the object.

Table 7. The specification of the final design.

Volume (Liter)	Top Radius (m)	Bottom Radius (m)	Height (m)
10	0.136	0.068	0.680
Outlet Pipe Length (m)	**Inlet Radius (m)**	**Outlet Radius (m)**	
0.544	0.030	1.75×10^{-2}	



(a) **(b)**

(a) XY Section and **(b)** ZY Section

Figure 19. Section views of thermal analysis of final design.

All analyses were observed and the best ratios and dimensions were selected. A final analysis was made using these parameters for a volume of 10 liters and the amount of water production was calculated as 1.25 Liters per day.

3.5 Discussion

A lot of analyses were done in this study process and their results were shown with graphs and tables. In some cases, the results that were possible to produce were preferred rather than the best. The most important reason for this was that the device had to be suitable for the home environment. Another important issue was to manufacture the device with additive manufacturing method. Considering all these, analysis results were selected and the most appropriate design was created. In general, the analysis steps were very detailed and at least 4 analyzes were made for each variable, the reason for this was to obtain correct results. The boundary conditions of all analyses on the program were checked and the continuity test results of the analysis were also examined.

4. MATLAB ALGORITHM

The reason for writing an algorithm is to observe how much water is produced at different temperatures at different hours of the day. While doing this study, the authors chose a random day from the city of Antalya in July 2019 and calculated the water production amount using the temperature and relative humidity values of that day.

4.1. Assumptions and Methods for the Algorithm

The authors started the preparation of the algorithm by recording the temperature and relative humidity values of the selected day in an excel file. After these data were obtained, thermal conductivity (k), thermal diffusivity (α), kinematic viscosity (ν), Prandtl number (Pr), and density (ρ) values corresponding to each hour were found by using the interpolation method.

$$\frac{T_{in}-10^\circ}{20^\circ-1\ ^\circ}=\frac{k_{Tin}-k_{10^\circ}}{k_{20^\circ}-k_{10^\circ}} \tag{4.1}$$

It was explained in *Equation 4.1* that the thermal conductivity value at a temperature value between 10 degrees and 20 degrees was found by interpolation. The interpolation method shown in the example was also used to find the values of thermal diffusivity, density, Prandtl number and kinematic viscosity. The values prepared for the air inlet are transferred from excel to the program and the matrix of each variable is created. While the calculations were made, the air inlet velocity was assumed as constant and 0.6 m/s.

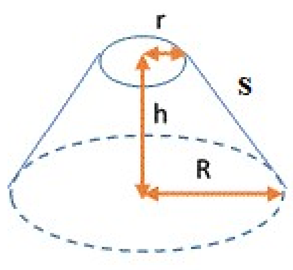


Figure 20. Truncated Cone

$$Surface\ Area = \pi\ x\ s\ x\ (R + r) \tag{4.2}$$

$$L_C = \frac{Volume}{Surface\ Area} \tag{4.3}$$

In *Equation 4.2*, the area of the cooling surface in the truncated cone was found. The characteristic length was calculated, using *Equation 4.3,* by dividing the constant volume and area of the cooling surface.

$$Nu = 0.664\ x\ (Re^{0.5})\ x\ (Pr^{\frac{1}{3}}) \tag{4.4}$$

$$h_{in} = \frac{k_{in}}{L_C}\ x\ Nu \tag{4.5}$$

As a continuation of these stages, Nusselt number and heat transfer coefficient were calculated. *Equation 4.4* and *Equation 4.5* were used when calculating the values. While performing the calculations, the flow was assumed to be laminar and the formulas were selected in accordance with the laminar flow.

$$\dot{Q} = h_{in}\ x\ A_{Surface}\ x\ (T_{in} - T_{out}) \tag{4.6}$$

Equation 4.6 was used to find the outlet temperature. The reason for using this formula is that the working principle of the system is forced convection. The formula calculates the outlet temperature depending on the energy received by the cold surface regardless of time. The energy used here is the cooling capacity provided by 3 Peltiers mentioned earlier.

After the outlet temperature was found, the relative humidity of the exiting air was considered 100%. In order to perform the interpolation process, the humidity ratios at certain temperatures were defined in the algorithm. To find the humidity ratio of the air at the outlet, the interpolation process mentioned in *Equation 4.1* was done. By using *Equation 6* and *Equation 7*, each hour of water production was calculated separately. A for loop was written to collect the water produced every hour with the previous hours.

Table 8. Temperature, Relative Humidity and Humidity Ratio for a random day in Antalya July, 2019.

Hour	Temperature(C°)	Relative Humidity(%)	Humidity Ratio(g/kg)
00:00	28	70	16.756
01:00	27	70	15.779
02:00	26	65	13.770
03:00	25	69	13.775
04:00	25	65	12.960
05:00	26	54	11.397
06:00	27	45	10.053
07:00	29	40	10.040
08:00	32	31	9.226
09:00	36	25	9.299
10:00	37	19	7.700
11:00	38	21	8.702
12:00	36	32	11.952
13:00	33	59	18.860
14:00	34	44	14.779
15:00	33	52	16.563
16:00	35	36	12.741
17:00	35	34	12.020
18:00	31	66	18.841
19:00	30	66	17.763
20:00	28	79	18.976
21:00	28	79	18.976
22:00	28	74	17.740
23:00	28	70	16.756

The reason for choosing Antalya while taking these data is that it has high relative humidity and temperature as mentioned before. The reason for choosing July also depends on the same factors. The temperature and relative humidity values shown for each hour in *Table 8* are taken from the "Weather Underground" website. With help of these values, humidity ratio was found with the help of psychrometric chart. All of this data is taken from the excel file defined in the algorithm when the codes given below are executed.

4.2 Matlab Codes

```
% Calculating the water harvested according to hourly weather and
humidity changes in a certain day in Antalya%

%Interpolation Part of Given Quantities in Formula%
%Thermal Conductivity of air [W/m.K] %
k_15=0.02476; % Thermal Conductivity of air at 15 degree C %
k_20=0.02514; % Thermal Conductivity of air at 20 degree C %
k_25=0.02551; % Thermal Conductivity of air at 25 degree C %
k_30=0.02588; % Thermal Conductivity of air at 30 degree C %
k_35=0.02625; % Thermal Conductivity of air at 35 degree C %
k_40=0.02662; % Thermal Conductivity of air at 40 degree C %
k_45=0.02699; % Thermal Conductivity of air at 45 degree C %

%Thermal Diffusivity of air [m^2/s]
a_15=2.009*(10^-5); % Thermal Diffusivity of air at 15 degree C %
a_20=2.074*(10^-5); % Thermal Diffusivity of air at 20 degree C %
a_25=2.141*(10^-5); % Thermal Diffusivity of air at 25 degree C %
a_30=2.208*(10^-5); % Thermal Diffusivity of air at 30 degree C %
a_35=2.277*(10^-5); % Thermal Diffusivity of air at 35 degree C %
a_40=2.346*(10^-5); % Thermal Diffusivity of air at 40 degree C %
a_45=2.416*(10^-5); % Thermal Diffusivity of air at 45 degree C %

%Kinematic Viscosity of air [m^2/s] %
v_15=1.470*(10^-5); % Kinematic Viscosity of air at 15 degree C %
v_20=1.516*(10^-5); % Kinematic Viscosity of air at 20 degree C %
v_25=1.562*(10^-5); % Kinematic Viscosity of air at 25 degree C %
v_30=1.608*(10^-5); % Kinematic Viscosity of air at 30 degree C %
v_35=1.655*(10^-5); % Kinematic Viscosity of air at 35 degree C %
v_40=1.702*(10^-5); % Kinematic Viscosity of air at 40 degree C %
v_45=1.750*(10^-5); % Kinematic Viscosity of air at 45 degree C %

%Prandtl Number %
Pr_15=0.7323; % Prandtl Number 15 %
Pr_20=0.7309; % Prandtl Number 20 %
Pr_25=0.7296; % Prandtl Number 25 %
Pr_30=0.7282; % Prandtl Number 30 %
Pr_35=0.7298; % Prandtl Number 35 %
Pr_40=0.7255; % Prandtl Number 40 %
Pr_45=0.7241; % Prandtl Number 45 %

%Density of air [kg/m^3]%
Ro_15=1.225; % Density of air at 15 degree C %
Ro_20=1.204; % Density of air at 20 degree C %
Ro_25=1.184; % Density of air at 25 degree C %
Ro_30=1.164; % Density of air at 30 degree C %
Ro_35=1.145; % Density of air at 35 degree C %
Ro_40=1.127; % Density of air at 40 degree C %
Ro_45=1.109; % Density of air at 45 degree C %

% Bringing the given values of Antalya from Excel%
experiment=xlsread('antalyaweatherforecast.xlsx');
T_in=(experiment(:,2));
w_in=(experiment(:,4)).*(10^-3);
v= 0.6; %inlet velocity m/s%
```

```
% Calculating Thermal Conductivity according to input Temperatures%
if T_in == 15;
    k_in=k_15;
elseif T_in<20;
    k_in=(((T_in-15)/(20-15))*(k_20-k_15))+k_15;
elseif T_in==20;
    k_in=k_20;
elseif T_in<25;
    k_in=(((T_in-20)/(25-20))*(k_25-k_20))+k_20;
elseif T_in==25;
    k_in=k_25;
elseif T_in<30;
    k_in=(((T_in-25)/(30-25))*(k_30-k_25))+k_25;
elseif T_in==30;
    k_in=k_30;
elseif T_in<35;
    k_in=(((T_in-30)/(35-30))*(k_35-k_30))+k_30;
elseif T_in==35;
    k_in=k_35;
elseif T_in<40;
    k_in=(((T_in-35)/(40-35))*(k_40-k_35))+k_35;
elseif T_in==40;
    k_in=k_40;
elseif T_in<45;
    k_in=(((T_in-40)/(45-40))*(k_45-k_40))+k_40;
elseif T_in==45;
    k_in=k_45;
end

% Calculating Thermal Diffusivity according to input Temperatures %
if T_in==15;
    a_in=a_15;
elseif T_in<20;
    a_in=(((T_in-15)/(20-15))*(a_20-a_15))+a_15;
elseif T_in==20;
    a_in=a_20;
elseif T_in<25;
    a_in=(((T_in-20)/(25-20))*(a_25-a_20))+a_20;
elseif T_in==25;
    a_in=a_25;
elseif T_in<30;
    a_in=(((T_in-25)/(30-25))*(a_30-a_25))+a_25;
elseif T_in==30;
    a_in=a_30;
elseif T_in<35;
    a_in=(((T_in-30)/(35-30))*(a_35-a_30))+a_30;
elseif T_in==35;
    a_in=a_35;
elseif T_in<40;
    a_in=(((T_in-35)/(40-35))*(a_40-a_35))+a_35;
elseif T_in==40;
    a_in=a_40;
elseif T_in<45;
    a_in=(((T_in-40)/(45-40))*(a_45-a_40))+a_40;
elseif T_in==45;
    a_in=a_45;
end
```

```
% Calculating Kinematic Viscosity according to input Temperatures %
if T_in==15;
    v_in=v_15;
elseif T_in<20;
    v_in=(((T_in-15)/(20-15))*(v_20-v_15))+v_15;
elseif T_in==20;
    v_in=v_20;
elseif T_in<25;
    v_in=(((T_in-20)/(25-20))*(v_25-v_20))+v_20;
elseif T_in==25;
    v_in=v_25;
elseif T_in<30;
    v_in=(((T_in-25)/(30-25))*(v_30-v_25))+v_25;
elseif T_in==30;
    v_in=v_30;
elseif T_in<35;
    v_in=(((T_in-30)/(35-30))*(v_35-v_30))+v_30;
elseif T_in==35;
    v_in=v_35;
elseif T_in<40;
    v_in=(((T_in-35)/(40-35))*(v_40-v_35))+v_35;
elseif T_in==40;
    v_in=v_40;
elseif T_in<45;
    v_in=(((T_in-40)/(45-40))*(v_45-v_40))+v_40;
elseif T_in==45;
    v_in=v_45;
end

% Calculating Prandtl Number according to input Temperatures %
if T_in==15;
    Pr_in=Pr_15;
elseif T_in<20;
    Pr_in=(((T_in-15)/(20-15))*(Pr_20-Pr_15))+Pr_15;
elseif T_in==20;
    Pr_in=Pr_20;
elseif T_in<25;
    Pr_in=(((T_in-20)/(25-20))*(Pr_25-Pr_20))+Pr_20;
elseif T_in==25;
    Pr_in=Pr_25;
elseif T_in<30;
    Pr_in=(((T_in-25)/(30-25))*(Pr_30-Pr_25))+Pr_25;
elseif T_in==30;
    Pr_in=Pr_30;
elseif T_in<35;
    Pr_in=(((T_in-30)/(35-30))*(Pr_35-Pr_30))+Pr_30;
elseif T_in==35;
    Pr_in=Pr_35;
elseif T_in<40;
    Pr_in=(((T_in-35)/(40-35))*(Pr_40-Pr_35))+Pr_35;
elseif T_in==40;
    Pr_in=Pr_40;
elseif T_in<45;
    Pr_in=(((T_in-40)/(45-40))*(Pr_45-Pr_40))+Pr_40;
elseif T_in==45;
    Pr_in=Pr_45;
end
```

```
% Calculating Density according to input Temperatures %
if T_in==15;
    Ro_in=Ro_15;
elseif T_in<20;
    Ro_in=(((T_in-15)/(20-15))*(Ro_20-Ro_15))+Ro_15;
elseif T_in==20;
    Ro_in=Ro_20;
elseif T_in<25;
    Ro_in=(((T_in-20)/(25-20))*(Ro_25-Ro_20))+Ro_20;
elseif T_in==25;
    Ro_in=Ro_25;
elseif T_in<30;
    Ro_in=(((T_in-25)/(30-25))*(Ro_30-Ro_25))+Ro_25;
elseif T_in==30;
    Ro_in=Ro_30;
elseif T_in<35;
    Ro_in=(((T_in-30)/(35-30))*(Ro_35-Ro_30))+Ro_30;
elseif T_in==35;
    Ro_in=Ro_35;
elseif T_in<40;
    Ro_in=(((T_in-35)/(40-35))*(Ro_40-Ro_35))+Ro_35;
elseif T_in==40;
    Ro_in=Ro_40;
elseif T_in<45;
    Ro_in=(((T_in-40)/(45-40))*(Ro_45-Ro_40))+Ro_40;
elseif T_in==45;
    Ro_in=Ro_45;
end

% Given Quantities of Design %
r=0.03;                               % Inlet radius [m] %
A=pi*(r^2);                           % Inlet area [m^2] %
V_Dot=v*A;                            % Volumetric flowrate at inlet
                                       [m^3/s]%
Re=v*(2*r)./v_in;                     % Reynolds number for air %
m_Dot_Air= Ro_in* V_Dot;              % Mass flow rate of air [kg/s]%
Area_Surface=0.4375;                  % Area of cold surface [m^2]%
Volume=0.01;                          % Volume of object [m^3]%
Lc=(Volume/Area_Surface);             % Charactheristic length [m]%
Nu=0.664.*(Re.^0.5).*(Pr_in.^(1/3)); % Nusselt Number%
h_in=(k_in./Lc).*Nu;                  % Heat transfer coeefficient
                                       [W/(m^2)K]%
Q_dot=180;                            % Heat consumption energy of 3
                                      peltiers [W]%
T_out=T_in -((Q_dot)./(h_in.*Area_Surface));  %Exit temperature
                                       [degree C]%

%Humid Ratios when humidity is  100%
w_10=7.661*(10^-3);  %Relative humidity at 10 degree C%
w_15=10.691*(10^-3); %Relative humidity at 15 degree C%
w_20=14.755*(10^-3); %Relative humidity at 15 degree C%
w_25=20.164*(10^-3); %Relative humidity at 15 degree C%
w_30=27.316*(10^-3); %Relative humidity at 15 degree C%
```

```
% Calculation Humidity Ratio at Outlet temperature%
for g= 1:25
   if T_out(g)==10;
    w_out(g)=w_10;
elseif T_out(g)<15;
    w_out(g)=(((T_out(g)-10)/(15-10))*(w_15-w_10))+w_10;
elseif T_out(g)==15;
    w_out(g)=w_15;
elseif T_out(g)<20;
    w_out(g)=(((T_out(g)-15)/(20-15))*(w_20-w_15))+w_15;
elseif T_out(g)==20;
    w_out(g)=w_20;
elseif T_out(g)<25;
    w_out(g)=(((T_out(g)-20)/(25-20))*(w_25-w_20))+w_20;
elseif T_out(g)==25;
    w_out(g)=w_25;
elseif T_out(g)<30;
    w_out(g)=(((T_out(g)-25)/(30-25))*(w_30-w_25))+w_25;
elseif T_out(g)==30;
    w_out(g)=w_30;
   end
end

% Modification to keep inıtıal poınt of harvested water at 'zero'%
T_out(1)=0;
w_out(1)=0;
w_out=transpose(w_out);

t=3600;                          % Time interval of 1 hour in one day%
m_Air=m_Dot_Air*t;               % Total air mass in the system%
m_Water=(m_Air).*(w_in-w_out);   % Total water mass in the interval%
T=t/3600;                        % Modification to plot the graph
                                  readable%

% Addition part%
% If outlet humid ratio less than inlet there is no water harvesting.%
for i= 2:25
if m_Water(i)<0
    m_Water(i)=0;
else m_Water(i)=m_Water(i);
end
end

% Water produced every hour is added with the previous hour%
for j=2:25;
    m_Water(j)=m_Water(j-1)+m_Water(j);
end

%Ploting part%
x=[0:1:24]; % Hours in the day %
plot(x,m_Water,'-b')
set(gca,'XTick',(0:1:24)) % Setting x-axis limits%
fprintf('Total water collected %4.2f Liter per day \n',m_Water(25))
title('Hourly Water Harvested in Antalya in a Day')
xlabel('Hours')
ylabel('Amount of Water Harvested')
legend('Real Cycle')
grid on
```

4.3. Matlab Results and Discussion

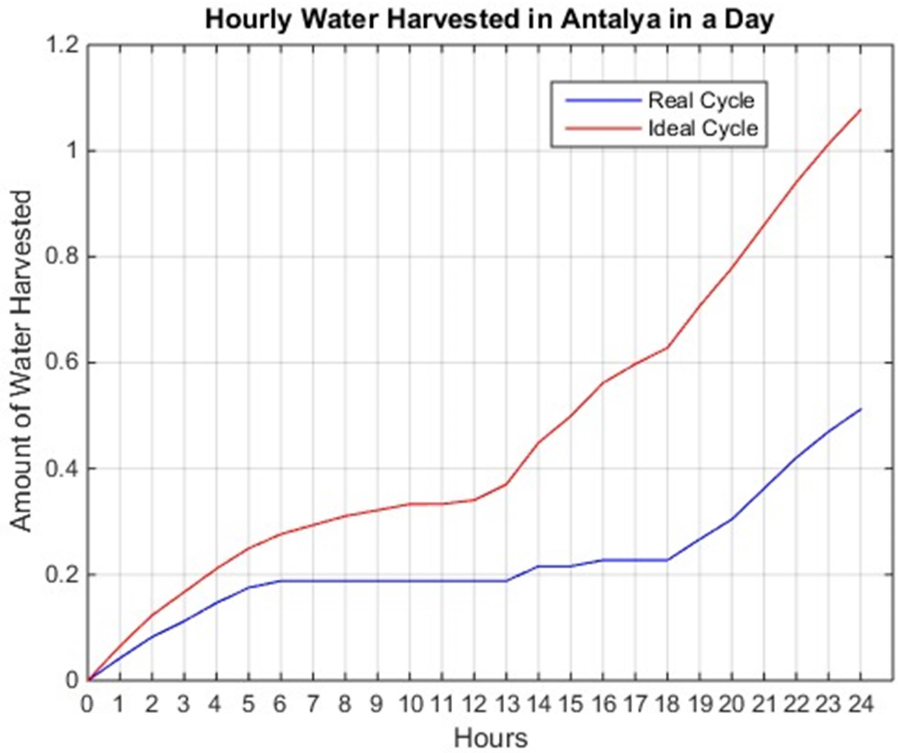


Figure 21. Graph of Ideal and Real Cycle.

When the above codes were run and calculated according to the actual cooling cycle, it was obtained that 0.51 L/day production was made. The red line in the *Figure 21.* corresponds to the ideal cycle. It is assumed that the air processed during the ideal calculation leaves the system at the same temperature as the cooling surface. As a result of this ideal calculation, the amount of production on a random day selected in July 2019 was found to be 1.08 L/day.

As observed in these data, there is a half loss between ideal and real results. As can be guessed, it was not possible to reduce the air temperature to the coolant surface temperature. It is observed that both calculations in this graph increase irregularly. This means that each hour has a different relative humidity value. The relative humidity dropped during the daytime of the selected day brought production to a halt. In some cases, since the humidity ratio at outlet is higher than the humidity ratio at the inlet, operating between those hours is unreasonable for water production. The operation of the system during these hours only serves as a simple air conditioner. As can be seen from this graph, there are some optimal values for the efficient operation of the system and these can be obtained at certain hours.

5. CONCLUSION

The steadily decreasing drinking water in the world encouraged the authors to do this study. It was asked to prove that water production can be done beside of natural resources and this process can be done in the home environment. Many studies have been done before regarding this topic. The difference of this study from others is that the electricity consumption is less and the device is small and portable. In this study, the authors determined the environmental conditions for water production and the dimensions of the device to be used in this process, using theoretical knowledge and analysis programs. During this study, the previous studies were followed and the realism of the study was tested by comparing the results.

The authors considered several factors when deciding on the geometric shape of the device. The first was to ensure that the object was not too large and complex and air should be circulated several times in the body, thereby increase in the contact of air to the cooling surface could be obtained. In order to meet these conditions, it was decided that the volume of the body should have a narrowing shape. Another important point was that the water collection chamber had to be at the bottom of the object and not in the same place as the air outlet. Thus, it was decided that the shape of the truncated cone was suitable for this study. The most important decision made by the authors before starting this study was that the volume of the object should not be larger than 10 liters, to be portable. The last but no least important point is to decide how to calculate the dimensions of the object in line with this decision. Instead of using independent measurements, multiple objects with different sizes and 10 liter volume were designed by increasing or decreasing the proportion of certain dimensions such as top and bottom radius ratio etc. The aim is to relate every part of the object to each other. Object designs created using the methods mentioned previously were tested using analysis and 3D design programs.

Other factors examined by the authors during this study are the temperature and relative humidity of the air, air inlet velocity, and cooling surface temperature. Researches were conducted for air temperature and relative humidity, and the values deemed appropriate were accepted for use in this study. In order to decide the inlet velocity of the air, detailed analyses with different velocity values were made for each design mentioned earlier. It was important to carry out these analyzes because the increase or decrease in velocity directly affects the mass flow rate of air at the inlet. The low mass flow rate of air caused the production to be insufficient, but the excess amount caused the cooling capacity to be insufficient. Thus, with the help of the analyses it is been decided the optimum inlet velocity for each design. The cooling surface temperature was chosen by the authors to be at 10 degrees. When deciding on this it is been considered if the Peltier devices which to be used for cooling process can provide this temperature regularly. Selecting higher temperatures will lower the electricity consumption but also the cooling capacity. However it was decided that it would not be possible to supply lower temperatures regularly with the help of Peltier devices.

In this study, the best dimensions of a truncated cone with a volume of 10 liters were obtained. With the help of the data obtained, final designs and analyses were made. As a result of these analyses, it was observed that 1.25 liters of water can be produced daily with the help of this device. The water obtained with the help of a device like this was considered sufficient.

It was observed by the authors that this study could be further developed and the dimensions of the design could be changed according to the needs. By determining and developing a precise method for the manufacturing, larger devices can be designed and more water can be produced. This device is intended for home use by the authors. For this reason, dimensions are preferred within a certain limits. It is possible to make changes in the size of the device according to the areas needed. It is obvious that this design can be improved, especially for use in military areas or camper vans. It is thought that this issue will be on the agenda in the future. This study is expected to guide future studies.

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