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Original Article

Design and Simulation of Sea Water Desalination using Renewable Energy

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Abstract *- The ideology behind using this method is to provide purified water at a lower cost and with less energy consumption along with environmental concerns, compact in design, and portable. Serve the need of single or multiple families. Stainless steel 316 material was selected for the boiling unit regarding the saltwater corrosion resistance. The design done in this paper is by using Solidworks software along with Solidworks flow simulation (for heat transfer analysis). The tube and heat chamber is where we performed our computational fluid dynamics analysis. Since the heat transfer occurs across the tube, the internal surface controls the heat transfer process. CFD heat transfer analysis has provided the output temperature and heat transfer behavior. After giving the boundary condition to the inner and outer fluid, the number of iterations is set to 400, the solution is calculated, and various contours, vectors, and plots are obtained. The average temperature of the steam is 42.48 °C, and the water outlet temperature is 38.22 °C. The condensation formed on conditions such as at 1 absolute bar pressure, latent heat 2237.79 kJ/kg is 10.748 kg/hr. The design process is viable during the sun peak hours.*

Keywords *- Desalination, Solar Energy, Heat Exchanger, Purification, Solidworks software.*

I. INTRODUCTION

Water is one of the most abundant things on the earth, yet the availability of safe and clean drinking water is a challenge for many people around the world. Only 3% of the total water on earth is fresh and drinkable, while a very small percentage of this freshwater, about 0.001%, is available to humans. Even this small fraction is believed to be adequate to support life on earth, but freshwater demand increases day by day due to the increasing population. Water is correlated to the evolution of civilization.

The utility of this project is to bring forth a new design system to be of assistance for the arid and semi-arid areas where plenty of underground water is available but is highly saline, which makes it unhealthy for humankind.

Surface water and groundwater are the exclusive resources of drinking water. Water from each source of these sources contains various dissolved solids that contaminate it. Poorly developed infrastructure is one of the causes that create a hurdle in the management, filtration, storage, and water supply. For safe water, sediments from the water must be removed, and microbes must be removed.

Desalination is one of the techniques in which low-grade solar energy operates directly with the help of solar radiation. With the growing demand for energy, environmental concern, and fast run out of non-renewable energy sources, it is necessary to use the renewable energy sources for various applications. Solar energy is one of the renewable energy sources necessary to be utilized for the socio-economic development of a nation [1-3].

II. METHOD & CALCULATION

A. Working on the Model

The principle behind our designed solar water desalination system is simple yet effective. The process begins when sun wave radiation gets absorbed by solar panels and converts solar thermal energy to electrical energy. That energy is stored in a battery to provide electricity to the heating coil installed in the boiling unit. The water then flows through the pipes to the boiling unit (where the desalination occurs). The seawater, after that, will gain heat through the heating coil. After the water is passed into the heat exchanger chamber to occupy liner volume, the condensation process will take place in the copper tube and then remove heat from the steam by the water surrounding the copper tube (increasing heat exchange rate). This process removes impurities such as salt and heavy metals and eliminates microbiological organisms. The condensed water is then stored in a tank where the reverse osmosis process is done. Desalination uses natural evaporation and condensation; this allows for natural pH buffering that produces excellent taste compared to distillation.

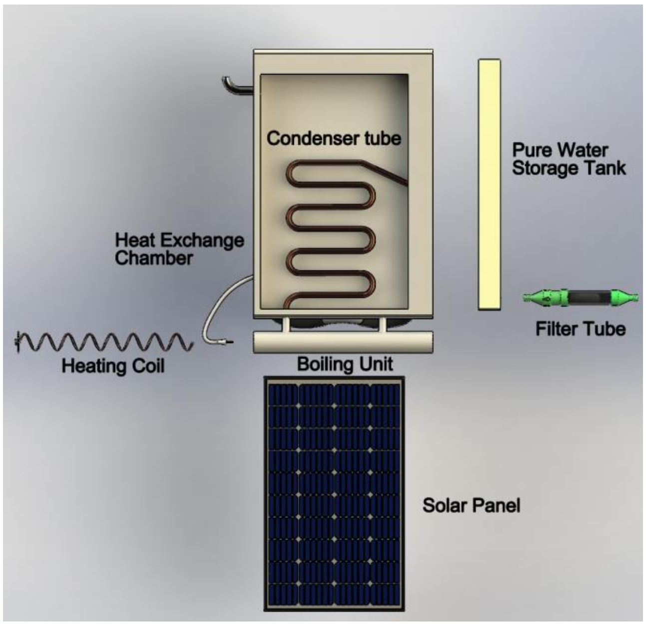

Fig. 1 Component view of the desalination system

B. Design calculation

a) Solar Panel

Considering the peak sun hours, which is in the morning between 10:00 am to 15:00 pm, so a total of 5 hours. Every solar panel cell produces 0.45 V to 0.6 V, hence taking V = 0.525 for one cell. The total number of cells in the panel is 60. We selected a solar panel generating power of 400 watts per hour [4-7].

Psolar panel = 3.00 KW h

$P = I \times V$

I = 14.28 Amp

Heat Flux Calculation

$T_2 = 150$ °C

$T_1 = 25$ °C

L = Length of heating element = 3.777 m

K = Thermal Conductivity = 11.3 W/m °C

Q/A = Heat flux

$Q^{\circ} = (T_2 - T_1) \times KA/L$

Heat Flux = 0.3739 KW/m^2

b) Boiling unit and heating element [5]

The heat required to convert water into steam

(Some standard values)

The heat of vaporization of water = 2257 J/g

Specific heat of water = 4.18 J/g °C

Specific heat of ice = 2.09 J/g °C

Specific heat of steam= 2.09 J/g °C

Heat required to raise the temperature of 25 °C water to 100 °C water.

q=mc(delta)T

q= (15000 g) (4.18 J/g °C) (75 °C)

q= 4702.5×10^3 J

Heat required to convert 100 °C water to 100 °C steam.

q= m(delta)Hv

q= 3385×10^3 J

Head Total = heat in step 1 + heat in step 2

= 38557×10^3 J

Heating effect of element can be given by

$E = I^2Rt$

E = 38577×10^3 J

T = 1800 s

I = 14.28

V = 31.5 V

Therefore, R = 105.04 = 106 ohm

ρ = Electrical Resistivity (μ Ω cm)

Element Resistance at 20 °C (Ω)

Therefore, cross-sectional area,

$A = \pi d^2/4$

A = 38.484 mm

R = (ρ × l / a) × 0.01

I = 3777.13 mm

As the temperature rises resistance rises

Electrical resistance at operating temperature

$R = R_t / F$

F = Temperature resistance factor = 1.015

R_t= 107.59 ohm

c) Heat chamber and tube

We used the virtual calculator to determine the condensate load from the heating liquid.

Heat transfer Q = U×A×(delta)×Tm

Plane wall heat transfer coefficient,

$U = 1/ (1/h_o + L/K + 1/h_1)$

Cylindrical wall heat transfer coefficient,

$U = 1/ (1/h_i + [Ro \times L_n \times (R_o/R_i)]/K + R_i/R_o)$

Table 1. Parameter for coiled tube heat exchanger

Temperature (Ta)	108.3 deg C
Temperature (Tb)	42 deg C
Tc	25 deg C
Td	38 deg C
The tube inside (Di)	25.27 mm
Tube outside (Do)	28.575 mm
The velocity of the fluid (V)	3.5 m/s

Table 2. Water properties at Tb deg C

Fluid density (ρ)	958 kg/m^3
Cp	4.2159kJ/kg K
Dynamic viscosity (μ)	1.79e-3kg/ms
Conductivity (k)	0.5 W/m K
Prandtl number (Pr)	6.9
Factor (n)	0.40
Velocity in the tube (V)	3 m/s

Table 3. Input steam table values

Absolute pressure		101.33
Evaporation Temperature		100
Specific Volume		1.67
Density		0.590
Specific enthalpy of evaporation	Liquid	419.1
	Evaporation	225.7
	Steam	2676

Table 4. Standard dimensions of copper tube

Nominal pipe size inches		1	
Outer diameter		1.125	
Inner diameter	Type	K*	0.995
		L**	1.025
		M***	1.055
		DWV****	-
Wall thickness		K	0.065
		L	0.050
		M	0.035
		DWV	-

K* - thick-walled
L** - medium walled
M*** - thin-walled
DWV**** - drain/waste/vent, non-pressurized

For normal warm up load, the quantity of condensate is,
Q = W (T-t) Sp. Heat 60/L m
W = 20 L 1 (m/1000 L)1000 (kg/m) = 20 kg
T = 100 °C
T = 25 °C
m = 15 min
Specific heat = 4.009 kJ/kg °C
At 50-psig (64.69 psia)
Latent heat (L) = 962 Btu/lb. = 2237.79 kJ/kg
So, we calculated by using the above equation:
Q = 10.748 kg/hr.
So, the condensation formed at the condition above is 10.748 kg/hr.

Table 5. The calculated result of the heat exchanger

Bulk temp. (Tb)	75.15 deg C
Reynolds number (Re)	4.43e+4 Turbulent>4000
Heat transfer coefficient (h)	5417 W/m^2 K
TBC	17 deg C
Tad	70.3 deg C
Tm	37.5 deg C
Uo	4791 W/m^2 K
Cp	4215.90 J/kg K
Tube length (L)	4.89 m

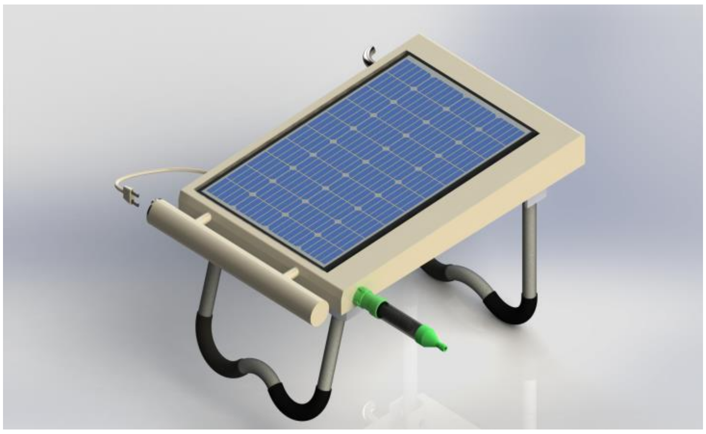

Fig. 2 Assembled view of design

Table 6. Selected materials for the components

Sr. No.	Components	Material
1.	Solar Panel	Poly-Crystalline
2.	Battery	$LiFePO_4$ []
3.	Boiling Unit	Stainless steel 316
4.	Heating Element	NiCr 80/20
5.	Tube	Copper
6.	Fresh Water Tank	Steel
7.	Filter	Plastic

III. RESULT AND DISCUSSION

A. Thermal Analysis

The induction heating coil works on the transformer principle. The current flowing in solid conductors creates ohmic losses (also called the joule effect) that contribute to heat in the workpiece. Therefore, the resistivities of the conduction materials and length and cross-section area are responsible for the ohmic losses [8].

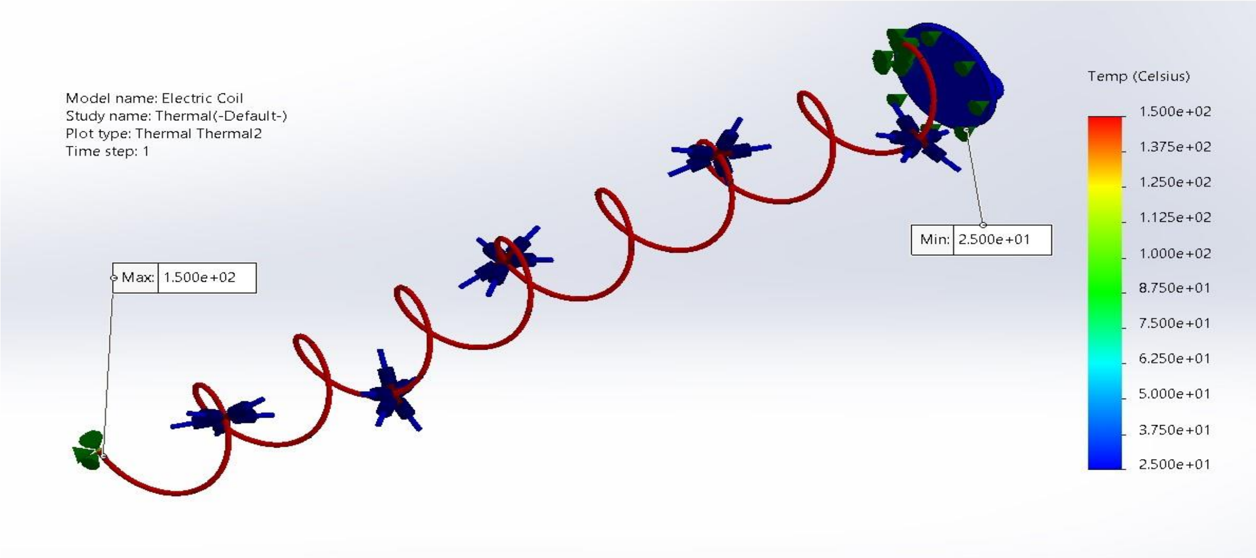

Fig. 3 Thermal analysis of heating coil

Table 7. Design Condition of the heating coil

Parameters		Values
Dia. of coil		7 mm
The cross-sectional area of the coil		38.484 mm
Length of coil		3777.12 mm
No. of coil turns		10
Temperature		150 C
Convection		60 W/(m K)
Result	Minimum	2.500e+01 C (Nodes: 2920)
	Maximum	1.500e+02 C (Nodes: 4304)

B. Computational Fluid Analysis: heat transfer analysis

Firstly, we determined the ability and purpose of the design condenser. The designed condenser is intended to increase the condensing rate and minimum length of the condenser tube to achieve the required condensation. The heat exchange chamber is designed to help cool the solar plate and increase the condensation rate by the temperature difference between the cold water in the chamber and the condenser tube, which consists of hot air. The design is done by reviewing the counter-flow heat exchanger concept and then seeking the length of the required tube. Later proceeded to make the design using CAD software and CFD heat transfer analysis.

a) CFD Analysis

Computational fluid dynamics (CFD) study of the system starts with the construction. The energy flow between hot and cold streams, with a hot stream in the tube, is as shown in the figure. Heat transfer mode is by convection on the inside and outside of the tube and conduction across the tube. Since the heat transfer occurs across the tube, this internal surface controls the heat transfer process. CFD heat transfer analysis analyzes the output temperature and heat transfer behavior [9-10].

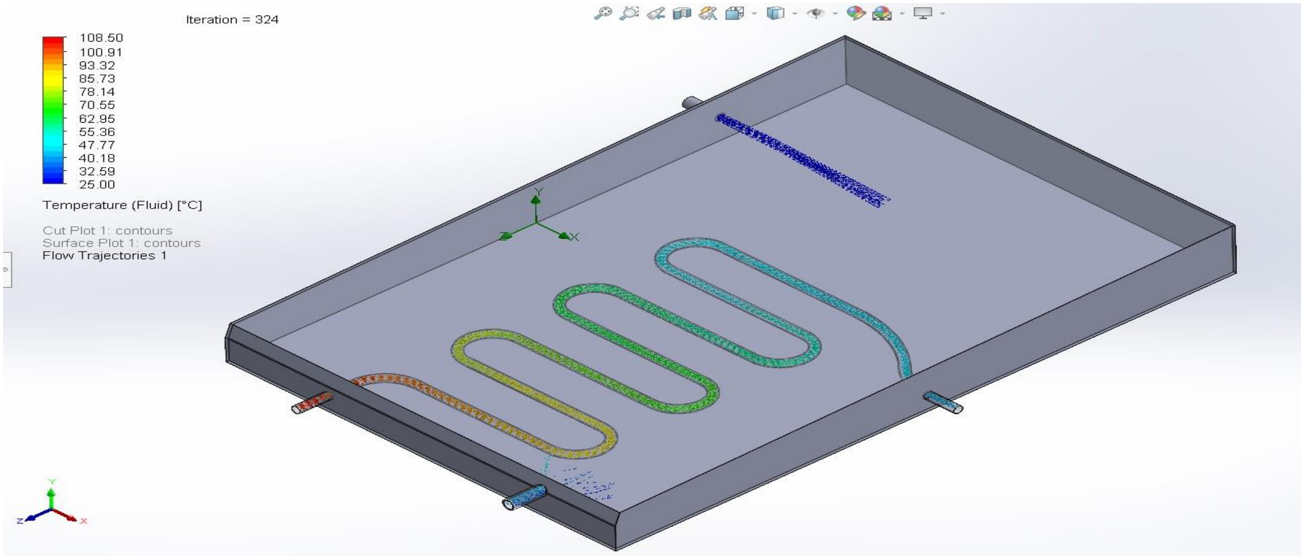

Fig. 4 Flow trajectory of heat exchanger

b) Geometry

The heat exchanger is built in the Solidworks design module and analyses in Solidworks flow simulation. It is the type of counter flow heat exchanger. First, the flow simulation wizard is selected.

c) The main solver

The solver is the main function of CFD software; it sets up the equation according to the options chosen by the user and meshes points generated by the pre-processor and solves them to compute the flow field. The process involves the following tasks:

Analysis type: internal flow simulation
Heat conduction in solids: on
Selection of fluid to be used in the analysis of heat exchange
Flow type: laminar and turbulent

d) Meshing

Initially, a relatively coarser mesh is generated. This mesh contains mixed cells (Tetra and hexahedral cells) with triangular and quadrilateral faces at the boundaries. Care is taken to use structural hexahedral cells as much as possible by structuring the mesh well, particularly near the wall region. Later on, a fine mesh is generated. The edges and regions of high temperatures and pressure gradients have finely meshed for this fine mesh.

Table 8. Fluid Subdomains

	Fluid subdomain 1	Fluid subdomain 2
Default fluid type	Gas/steam/real gas	Liquid
Fluids	Air	Water
Thermodynamic parameters	Static pressure: 101325.00 Pa Temperature: 108.50 °C	Static Pressure: 101325.00 Pa Temperature: 25 °C
Flow type	Laminar and turbulent	Laminar and turbulent

Table 9. Boundary conditions

Type	Flow parameters	Thermodynamic parameters
Inlet mass flow 1	Normal to face Mass flow rate: 0.0010 kg/s	Temperature: 25 °C
Inlet mass flow 2	Normal to face Mass flow rate: 0.0010 kg/s	Pressure: 101325 Pa Temperature: 108.50 °C
Environment pressure 1		Pressure: 101325 Pa Temperature: 108.50 °C
Environment pressure 2		Pressure: 101325 Pa Temperature: 25 °C

Table 10. Boundary condition of the wall

Type	Real wall
Heat transfer coefficient	60.000 $W/m^2/K$
Fluid temperature	25 C

e) Solution

After giving the boundary condition to the inner and outer fluid, finally, we have to run the calculations. The number of iterations is set to 400, the solution is calculated, and various contours, vectors, and plots are obtained.
Total cells: 106457
Fluid cells: 60749
Solid cells: 45708
Fluid cells contacting solid: 24611
Iteration: 324

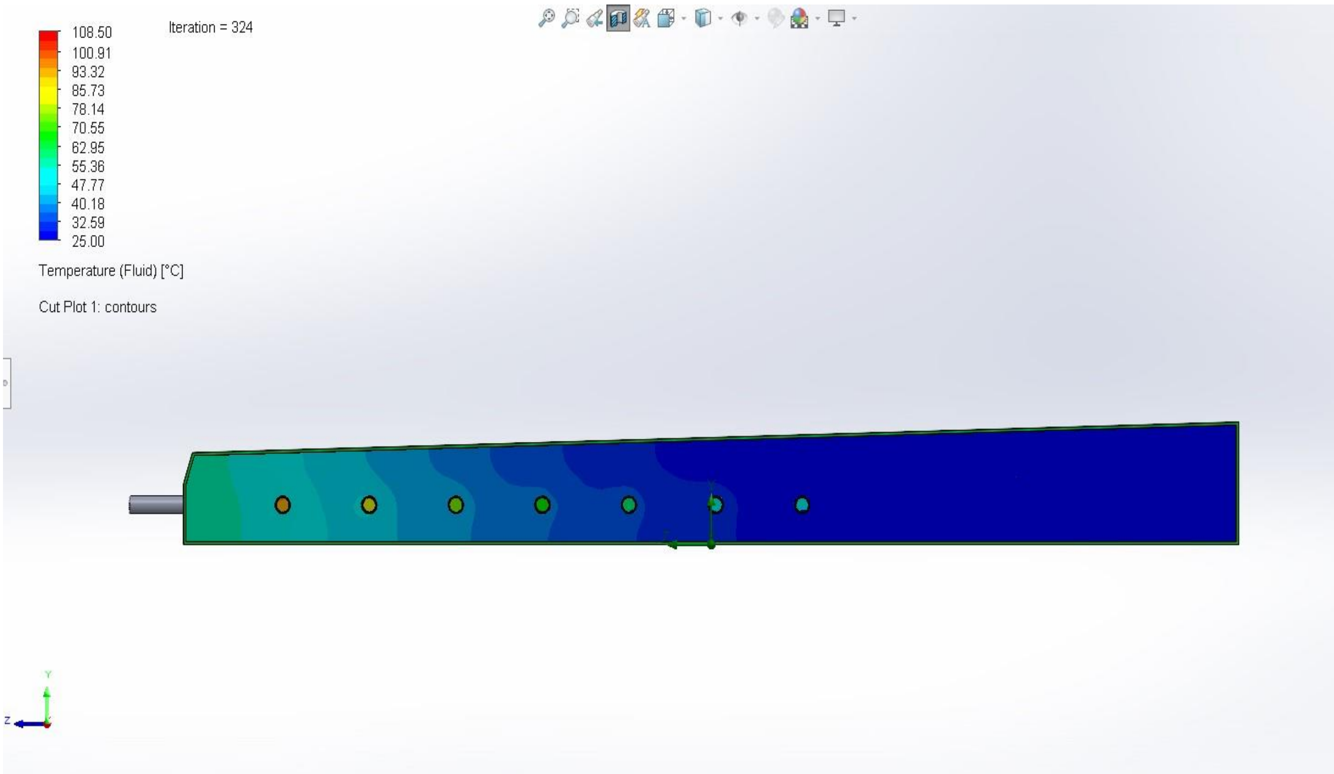

Fig. 5 Temp distribution in heat exchanger chamber

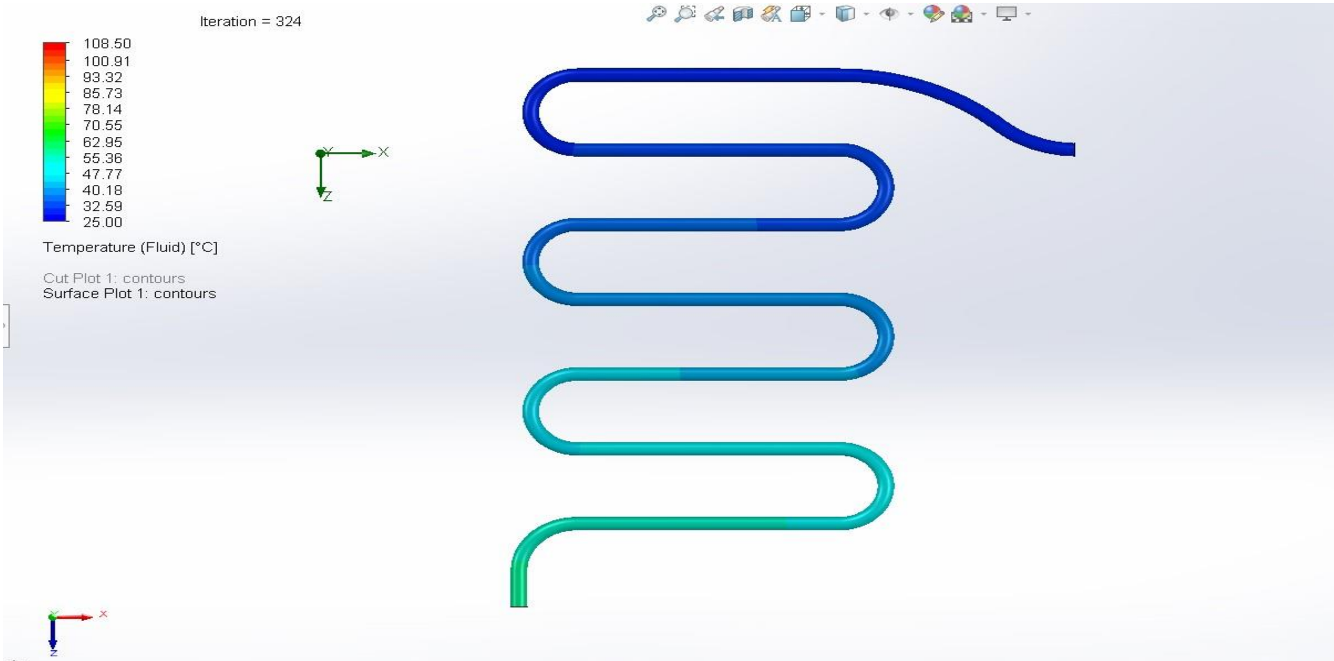

Fig. 6 Temperature distribution in condenser tube

Table 11. Goal result

Goal name	Unit	Value	Average value	Min. value	Max. value
Avg. outlet temp of steam	[C]	42.6	42.8	42.3	42.6
Water outlet temp	[C]	38.4	38.2	37.9	38.4

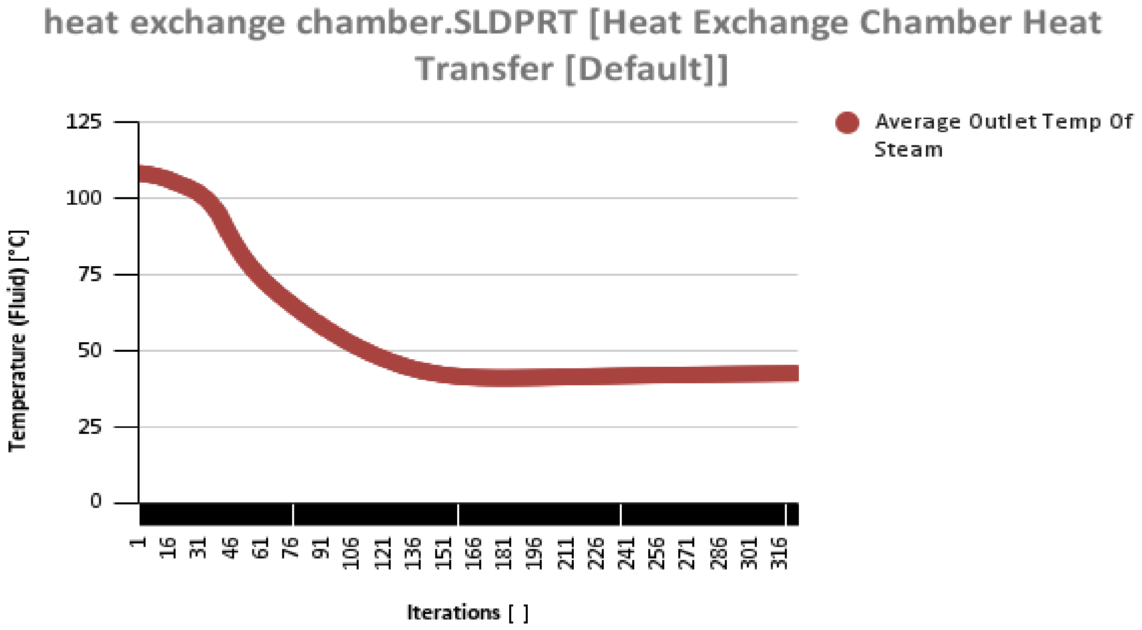

Fig. 7 Steam outlet temperature

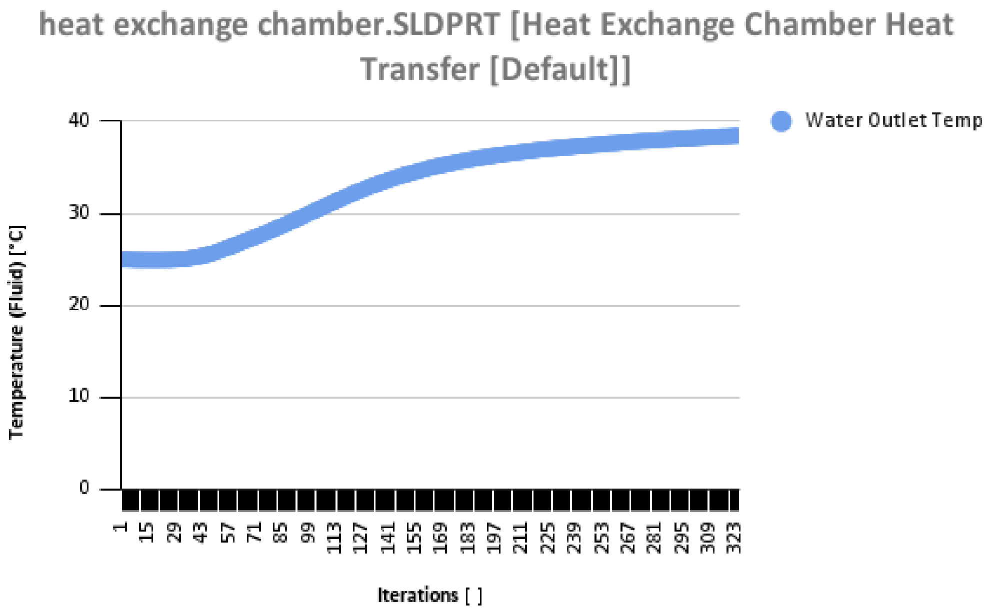

Fig. 8 Water outlet temperature

From the graph, the red line represents steam inside a tube surrounded by water in the chamber. The steam temperature decreases from 108.5 °C to 42.61 °C converting to liquid in the condenser tube. Also, from the computational analysis, it can be noted that the temperature of the water surrounding the condenser tube increases due to heat transfer, the variation is from 25 °C to 38.44 °C.

Table 12. The final output from the process

Components	Capacity
Boiling unit	20 lt.
Heat exchange chamber	150 lt.
Condenser tube	0.878 lt.
Storage tank (Purified water)	12 t.

IV. CONCLUSION

In this study of design and analysis of seawater desalination using renewable energy. The following conclusions are drawn:

- It is observed that the parameters have a statistically significant effect on the system's design.
- Placing the boiling unit at the bottom lessens the inlet (salty) water travel time.
- The condensation rate formed is 10.748 kg/hr.
- This design could solve the issues of water in arid and semi-arid areas. Delivering an adequate quality.
- The filter will be able to reduce the remaining impurities along with some chemical entities.

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