Optimization analysis of active solar still using design of experiment method

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Abstract:

The mathematical model for different configurations of active solar still has been analyzed. Theoretical analysis of energy balance for the active solar still components has been developed. A statistical manner for examination, evaluation, and optimizing the performance of the active solar distillation system with known input factors has been performed using the Design of Experiments (DOE) method. Some processes with input variables (factors) and predicted output variables (responses) have been evaluated. Input factors influencing the responses have been identified. The impact of each variable (factor) and the integration of two factors at the same time (called interactions) have been estimated. Influences of various factors on a particular study at a time rather than performing different separated studies have been investigated. 11 variables (basin area, depth of saline water, external power, air blowing system, condenser material, condenser thickness, condenser area, insulation thickness, insulation material, ambient air temperature, and make-up water system) have been studied to show their effects on three responses (mass output, saline water temperature and condenser cover temperature). The statistical results showed that the most significant factors affected mass output (distilled water) were the external power, the depth of the saline water, and the basin area of the active still, respectively. Furthermore, the most influential factors affecting the saline water temperature and the condenser cover temperature were the depth of saline water, external power, and air blowing system respectively.

Nomenclatures:

A_p	basin Area (m^2)
cp_b	Basin Specific heat (J/kg.k)
cp_w	Water Specific heat (J/kg.k)
cp_c	Condenser Specific heat (J/kg.k)
P_t	External power (W/m^2)
Q_{cb-w}	Convection heat transfer from basin plate to saline water (W)
Q_{cw-c1}	Convection heat transfer from saline water to the condenser (W)
Q_{rw-c1}	Radiation heat transfer from saline water to the inner condenser (W)
Q_{ew-c1}	Evaporation heat transfer from saline water to the inner condenser (W)
Q_{cw-c1}	Convection heat transfer from saline water to the inner condenser (W)
Q_{cc2-a}	Convection heat transfer from outer condenser cover to ambient (W)
Q_{rc2-sk}	Convection heat transfer from outer condenser cover to the sky (W)
$Q_{cnc1-c2}$	Conduction heat transfer from inner condenser cover to the outer condenser (W)
$Q_{loss-ba}$	Conduction heat transfer from basin plate to ambient (W)
Q_{mw}	Make-up saline water (W)
T_b	Basin temperature (C^o)
T_c	Condenser temperature (C^o)
T_w	Water temperature (C^o)
m_b	basin mass (Kg)
m_w	Inlet water mass (Kg)
m_c	Condenser mass (Kg)

1. Introduction:

Water is an essential component of human health. Nearly 60% of the human body is composed of water. It is important to note that the individual's need for water varies from person to another depending on the nature of the individual's daily physical activities and the drought proportion in the place where they live. Therefore, individuals tend to drink sufficient amounts of water to prevent them from the drought. Consequently, it leads to drain the body's energy, and cause tired. The National Academy of Sciences has determined the amount of water that is recommended daily, namely 3.7 liters of water for males and 2.7 liters of water for females. In fact, these amounts include water obtained from drinking water, and eating other foods and beverages. Although three-quarters of the earth is covered with water but, the clean water does not exceed 2.75%, which is a low proportion comparing with saltwater.

solar still is a green energy product that utilizes the natural energy of the sun to purify water. The solar-still process uses the sun instead of other sources such as fossil fuels to gain the energy needed for purification. Solar stills are then able to provide distilled water for cooking and drinking, even in areas where there are no other sources of energy, while still being friendly to the environment. The solar stills are broadly classified into two types namely, passive and active solar stills. active solar still uses some external setup like external power to feed an extra thermal energy for faster evaporation While Passive solar stills evaporate the basin water directly through sun. Design modifications of Active solar stills include solar still integrated with solar concentrators, solar still integrated with solar heater, and solar still with heat exchanger While passive solar stills include spherical solar still, wick type stills, etc.

The daily production and efficiency of a conventional solar still are relatively low. In best optimized operating conditions, daily production and efficiency are about 3-5 L/m^2.day and 30-45% respectively.[A. E. Kabeel and S. A. El-Agouz (2011)]. Numbers of attempts have been made to look for ways to inhace its efficiency and productivity. For more detail of the effective parameters of a conventional solar still, readers are referred to [Abujazar et al (2016), Sharshir et al (2016), Chandrashekara et al (2017)].

Improving the performance of solar still depends mainly on decreasing condenser cover temperature and increasing saline water temperature. Enhancing the productivity of solar still has received significant attention from many researchers. (Bataineh and Abu Abbas[a]; Manokar et al (2020) , Khalifa et al (2009); Zurigat et al. (2004), Madhlopa et al. (2009), The daily production of solar still depends on several factors such as climatic conditions [solar radiation intensity, ambient temperature, and wind speed], (Omar et al 2017, el-sebaii 2000) condensation surface inclination, (Bilal et al 2000) insulation type and thickness, (Manokar et al 2020) solar still geometry, (Mehrzad et al 2017) the orientation of still and depth of salty water, (Al-abed Allah and Abu Abbas 2020)

Bataineh and Abu Abbas[a] (2020) studied numerically the effect of solar still productivity by adding vertical fins, external reflectors and both of them together at different seasons. The theoretical results show that the productivity has not been affected significantly by adding fins and the efficiency of still increase by 13%, 20%, 28%, 33%, 37% and 46% in June, April, September, October, January, and December respectively when adding external reflectors. Bataineh and Abu Abbas[b](2020), Taamneh and Al-Abed Allah (2020) investigated theoretically and experimentally, the effect of single sloped solar still performance when adding Al_2O_3 and SiO_2 nanoparticles. The results show that the productivity of still boosted by 10% and 8.5%, respectively, at 0.005 m saline water depth and 0.2% concentration of nanoparticles. Manokar et al (2020) analyzed the performance of pyramid solar still at different saline water thickness, solar still with insulation material and solar still without insulation material. The experimental results inferred that the performance of still increase as saline water depth decrease and the productivity of still is improved 113 by integrate insulation material in the still. Khalifa et al (2009) verified the effect of insulation thickness (3, 6 and 10 cm) on the efficiency of solar still. The experimental results described that the productivity of still increase as insulation thickness increase up to specific value (6 cm) beyond which the effect of increasing thickness become insignificant. Abu Abbas and Al-Abed Allah (2020) examined numerically the impact of condenser materials type and condenser incline on the performance of the solar still under Jordan conditions. The results reveal that the daily solar still productivity increases as transmissivity value of condenser material increase. Also, it was noted that the maximum productivity in summer (May) was at the lowest condenser slope angle (5^o) and it was decreased as the condenser slope angle increased. On the other hand, the maximum productivity of solar still in the winter season (January) was at (20^o) and then decreased as the condenser slope angle increased. Dubey and Mishra (2019) examined the influence of three glass cover angles (15˚, 30˚, and 45˚) on solar still productivity. They found that the maximum productivity was obtained at 15˚ tilt angle which was nearer to the latitude of Raghogarh, Guna. Kumar et al. (2008) examined the V-type solar still with floating charcoal absorber over the saline water in basin liner and with and without the boosting mirror. The yield increases with boosting the mirror, but overall efficiency reduces due to an increase in loss and condensate could be easily collected because of the collection at the center. Madhlopa et al. (2009) found out that utilizing multi evaporators and multi condensers have improved the solar still performance by 62%. Hansen et al. (2017) enhanced solar still productivity by using fin shaped absorber configuration. Their results showed that the solar still efficiency increased by 25.75%. E. Kabeel et al. (2018) investigated the effect of utilizing a different type of phase change materials (PCM) to enhance solar still performance. The theoretical results showed that the A48 type of PCM has the highest increase in efficiency reach up to 92%. Al-harahsheh et al. (2018) conducted an experimental study on single slope solar still integrated with phase change material and connected with a solar water collector to enhance basin water temperature of solar still. Zurigat et al. (2004) studied the effect of a regenerative concept on solar still performance. Their results illustrated that the performance of regenerative still concept is higher by 20% compared with conventional solar still. Nisrin Abdelal et al. (2018) conducted an experiment to study the effect of using absorber plates made of carbon fiber/nanomaterials-modified epoxy composites at different concentrations. Their results show that the productivity of still increase by 109% and 65% when adding 5% and 2.5% Nano weight concentrations respectively. Agrawal et al. (2017) conducted experimental and theoretical study to investigate the effect of saline water depth (2 cm, 4 cm, 6 cm, 8 cm and 10 cm) on solar distillation system productivity. Their results illustrated that the distilled water of solar distillation system increases as decreasing water depth. Hitesh et al. (2012) examined the effect of floating plates (such as galvanized iron and aluminum) on solar still productivity. It was observed that the aluminum plate enhanced the productivity of still more than galvanized iron plate. Poblete et al (2016) investigated experimentally the effect of several factors on the efficiency of solar still such as heating of basin liner, condenser cover material, using reflectors (mirrors), air extractor, and the existence of a black-painted the floor in the solar still. The results showed that the factors (Mirror) and (Basin heated) are the most significant factors affecting productivity.

Design of Experiment is an efficient tool for increasing the quantity of data gained from a study in addition to reducing the amount of data to be obtained, which, in this case is decreasing the number of trial runs. It should be remarked that all the researches have studied the influence of utilizing one parameter at a time while keeping the other parameters fixed. this technique will not lead us to understand the interaction between factors. Here in this research, we collected all the parameters (basin area, depth of saline water, external power, air blowing system, condenser material, condenser thickness, condenser area, insulation thickness, insulation material, ambient air temperature, and make-up water system) have been studied to show their effects on three responses (mass output, saline water temperature and condenser cover temperature) that could affect the active solar still system to show which parameters have the most significant effect and which of them does not has any influence when they are being together at the same time. Moreover, to explain the interaction between the most significant factors and their regression equations. In addition to highlight on the most important factors that create the optimal design for active solar still system.

2. Methodology:

2.1 Description:

The main components of active solar distillation system are shown in Fig. 1. The water tank is used as a make-up water system to compensate for purified water. An external power device is used to heat the basin plate. A Large proportion of heat will transfer by convection to the saline water while the rest of it will be lost outside by conduction through the bottom and the sides of the still. The heat will be conveyed from the high saline water temperature to the internal surface of cooled condensation cover by evaporation, convection and radiation. The heated saline water will convey heat to the inner cooled condensation cover by evaporation, convection and radiation. Then part of the heat will be transferred by conduction between two sides (from the inner to the outer surface) of the condenser, and by radiation and convection from the upper surface of the condenser to the surrounding air. Inclined condensation cover is used to move evaporated water to the water collector. Bottom and all sides of solar distillation system have a specific insulation material with a proper thickness to eliminate heat losses from heated saline water to the surrounding. Moreover, Fig. 2a and Fig. 2b show solar still with increasing condensation cover area and adding fan respectively to enhance convection heat transfer from the upper surface of the inclined surface to the ambient air. as a result, increasing the condensation rate. Fig. 3 shows the distilled water cycle for solar distillation system.

2.2 Mathematical model:

A complete non-liner differential equations model that shows the heat transfer and energy processes in the main components of the active solar distillation system has been written. These equations helped to calculate the quantity of the distilled water temperature and the condenser cover temperature at any time and at different system configurations. The theoretical results were founded by solving the main energy balance equations for the basin plate, saline water, the inner and the outer condenser covers of the active solar distillation system. The saline water, the basin plate, the inner and the outer condenser cover temperatures were evaluated every 5 hours to show the effect of changing different parameters on the solar distillation system productivity. The numerical model was solved by Matlab software. Energy balance equations for main solar still components are presented as follow:

As shown in Eq. (1), a fraction of the external power connected with the solar distillation system is transmitted to the basin plate as heat and then it is transferred to saline water by convection. another amount of energy is lost to the ambient through bottom insulation material by conduction.

$$\mathrm{P_t A_b} = m_b cp_b \frac{dT_b}{dt} + Q_{cb-w} + Q_{loss-ba} \tag{1}$$

The transient energy balance equation for the saline water is given as Eq. (2),
A fraction of heat is transmitted to saline water by convection. All heat gained is lost in two approaches; a specific quantity of energy is stored in saline water due to its specific heat property. The rest of the energy is released to the inner condenser cover by evaporation, convection and radiation.

$$Q_{cb-w} = m_w cp_w \frac{dT_w}{dt} + Q_{cw-c1} + Q_{ew-c1} + Q_{rw-c1} + Q_{mw} \tag{2}$$

The energy balance equation for the inner condenser cover is presented as Eq. (3). The heat energy arrived from the saline water surface is absorbed by the inner condenser cover and then released by conduction through-thickness of the cover.

$$Q_{cw-c1} + Q_{ew-c1} + Q_{rw-c1} = m_c cp_c \frac{dT_{c1}}{dt} + Q_{cnc1-c2} \tag{3}$$

The energy balance equation for the outer condenser cover is shown as Eq. (4). The heat lost by conduction to the outer condenser cover is transferred by convection to the air and by radiation to the sky.

$$Q_{cnc1-c2} = m_c cp_c \frac{dT_{c2}}{dt} + Q_{rc2-sk} + Q_{cc2-a} \tag{4}$$

2.3 Design of Experimental:

Design of Experimental is a valuable tool for researchers and designers which is used to develop any system design. This tool can reduce designing time and cost with high reliability than other designing approaches. As it is known, the main purpose of conducting an experiment is to be found which system parameters have most significant on the specific response (output of the system). Using this tool, it will be known the effected factors that improve the system and neglect the fewer effected factors.

In this study, the factorial design has been used to determine the most influence and not influence of 11 factors, interaction between them and regression equations for designing solar distillation systems. Three responses have been evaluated which are distilled water, saline water temperature and inner condenser temperature.

2.3.1 Factorial Design:

A factorial design is an important type of design of experiments approaches. It is used to determine the most effected parameters to find the optimal design for the system of interest. Therefore, a huge time and tremendous effort could be saved instead of applying a full-scale simulation. Furthermore, the most valuable advantage of the factorial design is to find the regression equations and interactions between the factors that would be impossible to calculate in the other analysis approach. In order to achieve all the previous advantages, the factorial design method could set two values for each factor (levels), these levels and their values is determined by experience, then the researcher has to create configuration runs table using Minitab software according to probability counting rule ($2^{\wedge k}$) where k is the number of factors each one has two levels (+1 value for a high level and –1 value for a low level.). Table. 1 below displays the main factors of interest

2.3.2 Reduced Factorial $2^{\wedge(11-4)}$

The main purpose of reduced factorial design that the system is performed with much fewer trials by sacrificing interactions for more than three factors. The reduced factorial which has been selected is 2^ (k-r) where r refers to the number of reduced factors. Moreover, reduced factors have been chosen very carefully by checking the alias structure, resolution, balancing and orthogonally. In this study, a 2^(11-4) reduced factorial has been used with V resolution, which means that the main effects and two-way interactions are not confounded except with higher-order interactions. Matlab has been used to simulate the suitable and necessary simulations and Minitab to investigate the main influence factors and interactions between them with high accuracy.

3. Numerical simulation assessment

Fig. 4 shows the flowchart used to evaluate the most significant factors that have impacts on the solar distillation system. The simulation starts with the Minitab program to find the number of solar still configurations using 11 factors. Determine the type of analysis (reduced or full factorial), factors number and nature of runs (randomize or non-randomize runs) are the important steps in this software. Furthermore, a numerical model was written using the Matlab program to analyze the effect of the solar still configurations calculated using the Minitab program. Minitab is computer software that was developed to solve a mathematical model of the still components (condensation surface, saline water and basin plate) for different solar still configurations. The Temperature of the condensation cover, saline water and the basin plate were founded by solving the numerical model using Runge–Kutta method. All still components' temperatures and purified water were founded every 5 hours.

Initial temperature values of different components of the solar still were equaled the ambient temperature value. Using these initial temperatures, the condensation cover, saline water and the quantity of distilled water were calculated. The procedures were repeated for every solar still configuration (run) which was taken from the Minitab program. Finally, all solar still configurations results that calculated from the MATLAP were analyzed using the Minitab program to show their effects.

4. Results:

The results of mathematical and designing calculations could discover the effect of different factors on active solar still responses. Three responses have been studied: the amount of distilled water (mass output), water temperature, and condenser cover temperature. External power, basin area, water depth, insulation material, insulation thickness, condenser material (according to material thermal conductivity value), condenser area, thickness of condenser, air blowing system according to air speed (without air blowing = 0 m/s and with air blowing = 20 m/s) , Make-up water system, and ambient temperature are considered as variables to understand their influences on the mentioned responses. To be more effective, the simulation results were gained based on the design of the experiment approach (DOE). The (DOE) was conducted using a reduced factorial method to show their direct effects, their interactions, and the optimization design for the system.

4.1 Main effect plots on the responses:

Fig. 5a, Fig. 5b and Fig. 5c showed the main factors influenced on the responses of active solar still system. The x-axis shows responses values while the y-axis shows the high and the low levels of the factors. It was clearly noted that, as inclination of the lines increase, the effect of the factors on the responses will be significant. The results found that the most important factors that enhance mass output are the amount of external power, water depth, and basin area respectively. Where the mean mass output recorded at the high and low levels were 3.02 L and 1.24 L respectively for external power factor and 1.3L and 2.8L respectively for water depth factor. While, it is reached about 2.8L and 1.4L at high and low levels of the basin area respectively. Moreover, other factors have little effect on the system. The reason behind that can be explained in terms of the evaporation rate. As increasing the amount of external power, the basin water temperature increase. Therefore, the evaporation rate will be increased. Consequently, distilled water is boosted (Ahmed et al 2012). Moreover, as decreasing the basin water depth, the basin water temperature increases faster. Hence, the evaporation rate will be improved, and water productivity is enhanced (Agrawal et al. 2017). Furthermore, when increasing basin water area, the amount of distilled water is increased due to fact that the evaporation rate of the water in the solar still is directly proportional to the exposure area (V. Velmurugan and K. Srithar 2011). Also, as increasing the air speed on the upper condenser layer, the convection heat transfer is increased and then the condenser temperature will be decreased (El-Sebaii et al 2004). Furthermore, the simulation results indicated that the water depth, the amount of external power, the air blowing system, and the condenser material respectively are the main factors that have the most influence on the water temperature and condenser cover temperature of the system while the rest factors have a little effect on it as shown in Fig. 5b. and Fig. 5c.

4.2 Interaction effect plots:

The independent variables (factors) might interact with each other. It happens when the influence of one factor depends on the value of another factor. Moreover, the Interaction effects show that a third variable affects the relationship between an independent and dependent factor (responses). This kind of scheme represents the fit values of the dependent factor on the y-axis while the x-axis displays the values of the first independent factor while the different lines describe the values of the second independent factor. About the interaction schemes, parallel lines show that there is no interaction between the two factors while the crossed lines and the lines that will be crossed infer that there is an interaction effect between the factors. Here are the figures for the factors that produced an interaction between each other for various responses. Fig. 6a showed that the interaction effect on mass output. It was clearly noted that (basin area*external power), (basin area*depth of water), (depth of water*external power), (depth of water * air blowing system) and (condenser material *depth of water) respectively have the greatest interaction effect between each other. For example, the scheme for (basin area*external power) explains that the mass output level was higher when the external power and the basin area values were high. Conversely, the maximum mass output has been achieved when the external power and the basin area values were low. Fig. 6b showed the effect of the interaction on the water temperature of the active solar still .it was shown that the highest interaction to produce maximum water temperature was between (depth of water * air blowing system), (condenser material *depth of water), (depth of water*condenser area), (external power * air blowing system) and (depth of water*external power) respectively. For example, the charts for (depth of water*condenser area) and (depth of water*air blowing) describe that the water temperature level is higher at a low level of water depth, and when condenser material and air blowing at the low level also. On the other hand, at a high level of water depth, the water temperature remains as to whether the condenser material and air blowing are at a high or low level. While the interaction plot affected on condenser temperature was described in Fig. 6c. Whereas the important interaction effect was (depth of water * air blowing system), (condenser material *depth of water), (power * air blowing system), (depth of water*condenser area) and (depth of water*external power) respectively.

4.3 Pareto charts of the standardized effects:

Fig. 7 display the Pareto charts of the standardized effects for various responses. These charts determine the order of the most significant factors including main and interaction factors that effect on the response's values. It is clearly observed that the most influential factors on mass output are external power, depth of water, and basin area respectively. While in the water temperature and condenser cover temperature, the factors that have the most significant effect are depth of water, external power, and air blowing system respectively.

4.4 Regression equations:

Regression has been conducted on the results of factorial to show the effects of these factors on the response values. Eq. (5), Eq. (6), and Eq. (7) are the regression functions predicted from the reduced factorial study which found that the highest and lowest factors affected on three responses: distilled water, saline water temperature and condenser cover temperature respectively. The constant numbers refer to the factors affected ratio while the signals +, - refer to the high or low levels of the factors.

$$
\begin{aligned}
\text{Mass} = {} & -1.026 - 0.0349\,A - 8.1\,B + 0.480\,C + 17.52\,D + 0.0809\,E + 4.67\,F \\
& - 0.0715\,G + 0.000990\,H - 0.1068\,J + 0.00196\,K - 0.1711\,L \\
& + 2.406\,A{*}D - 23.92\,C{*}D + 0.005022\,C{*}H - 0.02169\,D{*}H \\
& + 3.194\,D{*}J + 1.554\,D{*}L
\end{aligned} \tag{5}
$$

$$
\begin{aligned}
\text{Tw} = {} & 16.72 + 4.36\,A + 3386\,B + 17.19\,C - 10.7\,D - 3.52\,E + 41.5\,F \\
& - 0.627\,G + 0.04329\,H - 4.11\,J + 0.0179\,K - 0.761\,L \\
& - 759\,A{*}B + 1.166\,A{*}E - 0.00571\,A{*}H - 2617\,B{*}C - 13448\,B{*}D \\
& + 58.2\,D{*}E - 0.1492\,D{*}H + 80.9\,D{*}J - 0.00433\,E{*}H + 1.545\,E{*}J - \\
& 0.00675\,H{*}J
\end{aligned} \tag{6}
$$

$$
\begin{aligned}
\text{Tc} = {} & 10.21 + 3.61\,A + 2095\,B + 0.70\,C + 97.3\,D - 3.20\,E + 50.4\,F \\
& - 0.397\,G + 0.04501\,H - 3.61\,J + 0.0436\,K - 1.013\,L - 1203\,A{*}B \\
& + 77.4\,A{*}D - 0.01053\,A{*}H - 1.815\,A{*}J - 18424\,B{*}D + 60.7\,D{*}E - \\
& 0.2414\,D{*}H + 92.2\,D{*}J - 0.00717\,E{*}H + 1.633\,E{*}J - 0.01207\,H{*}J
\end{aligned} \tag{7}
$$

4.5 Optimization Design:

The designers should create the system by selecting the value of the optimal factors that could enhance mass output. As mentioned above, the maximum water output produced from the solar still could be achieved by increasing the saline water temperature and decreasing the condenser cover temperature. Table. 2 and 3 list the fit values and optimal design selected respectively, to achieve the optimal value for the mass output, saline water temperature and condenser cover temperature.

5. Conclusion:

The results of theoretical and statistical analyses of 11 factors on the active solar still system could be summarized as follows:

- The most important factors that can cause increase in the mass output are the amount of external power, water depth, and the basin area respectively.
- The thickness of the condenser and the ambient air temperature do not affect the mean productivity
- Water depth, the amount of external power, the air blowing system, and the condenser material, respectively, are the main factors that have the most influence on the water temperature of the system.
- (Basin area*power), (basin area*depth of water), (depth of water*power), (depth of water * air blowing system) and (condenser material *depth of water), respectively, have the greatest interaction effect between each other that influence the mass output
- The significant interaction affected on saline water and the condenser temperatures are (depth of water * air blowing system), (condenser material *depth of water), (power * air blowing system), (depth of water*condenser area) and (depth of water*power) respectively.
- The optimal design for the system can be attained ~~is~~ by selecting:
  - Higher external power, basin area, condenser thickness, ambient temperature and insulation thickness.
  - Lower condenser area and depth of water.
  - Using steel condenser material and fiberglass insulations rather than any other materials.
  - Adding an air blowing system and removing the make-up system.

Conflict of Interest

The authors declare that they have no conflict of interest.

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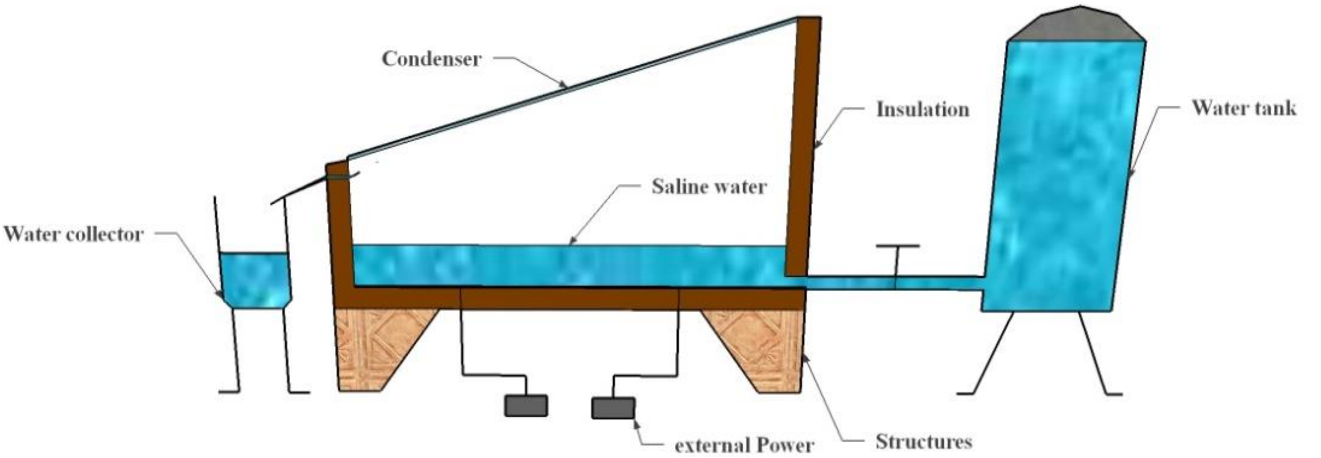
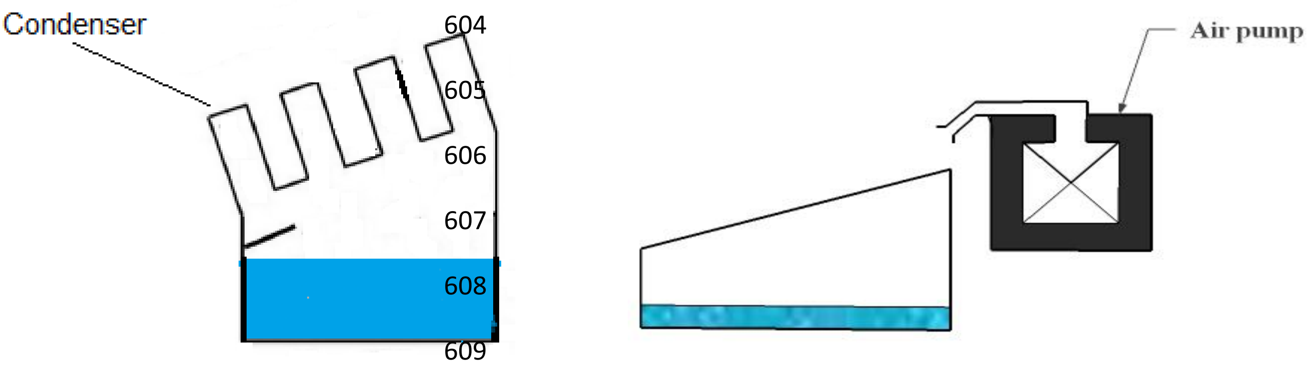


Figure 1. Solar distillation system.



(a) (b)

Figure 2. (a) increasing condensation cover area and **(b)** adding fan to solar still

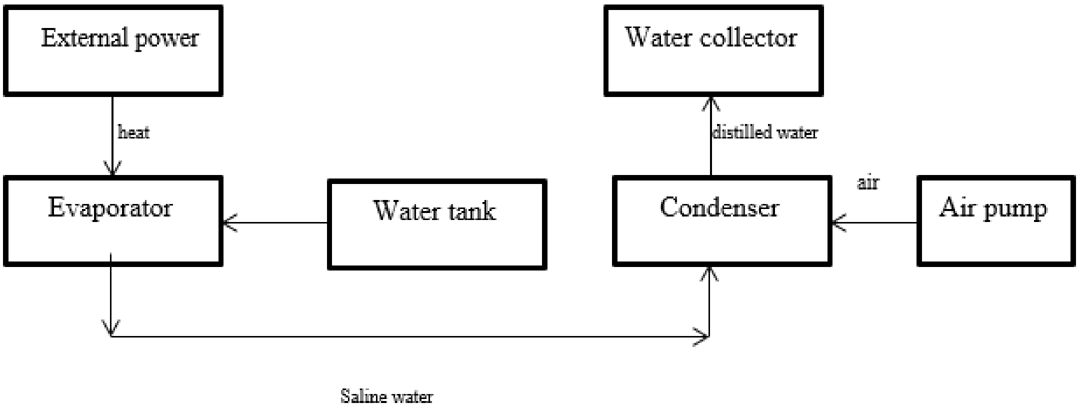


Figure 3. Distilled water cycle system.

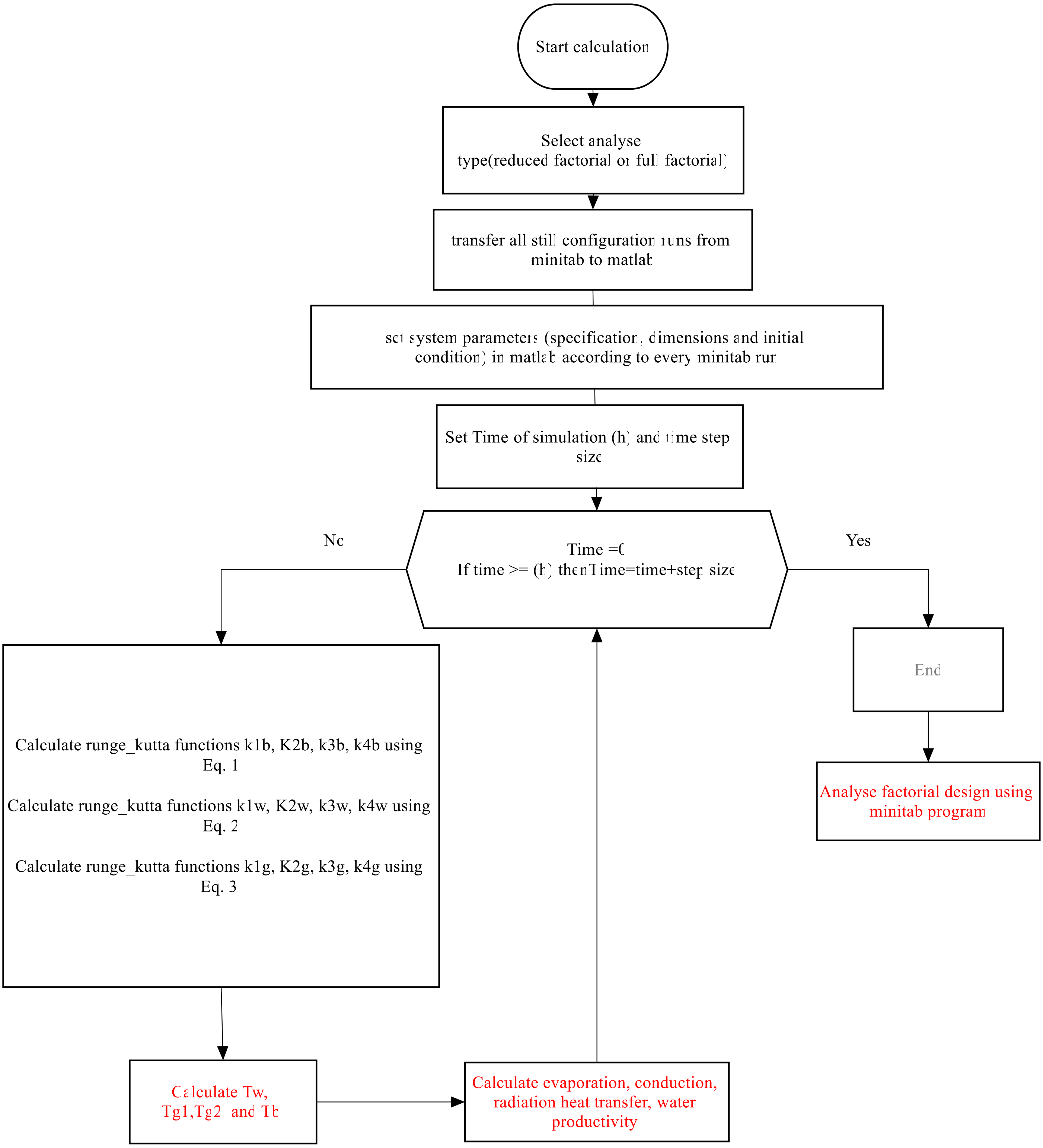
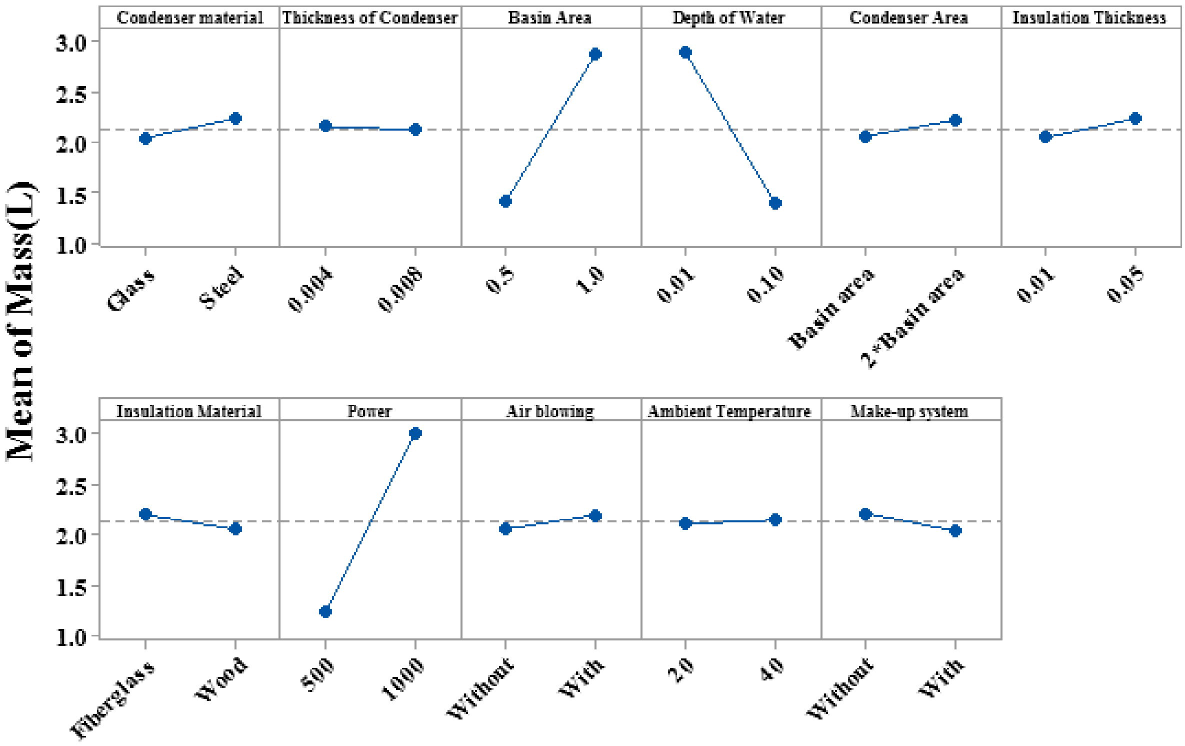
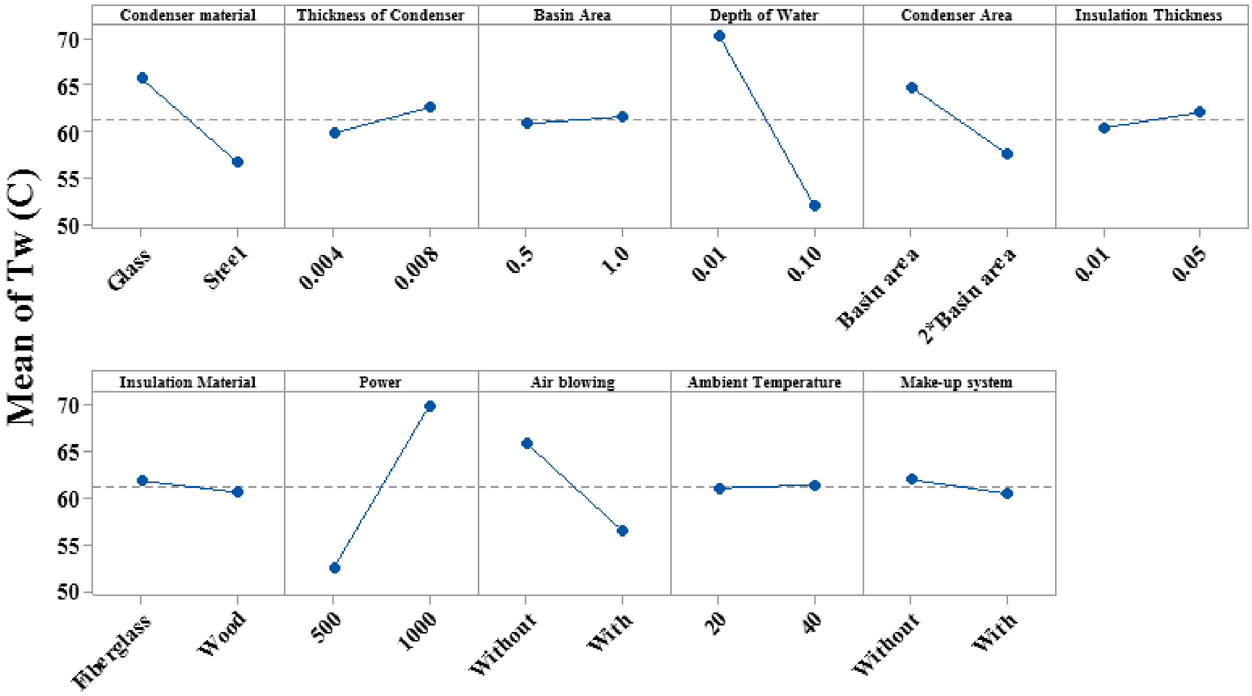


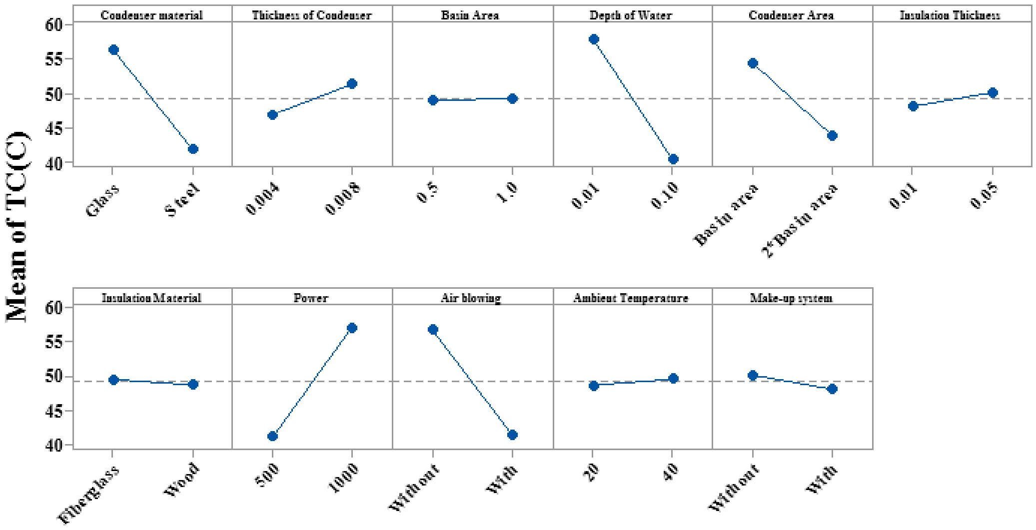
Figure 4. System flow chart


Mean of Mass(L)
Condenser material
Thickness of Condenser
Basin Area
Depth of Water
Condenser Area
Insulation Thickness
3.0
2.5
2.0
1.5
1.0
Glass
Steel
0.004
0.008
0.5
1.0
0.01
0.10
Basin area
2*Basin area
0.01
0.05
Insulation Material
Power
Air blowing
Ambient Temperature
Make-up system
Fiberglass
Wood
500
1000
Without
With
20
40
Without
With

(a)

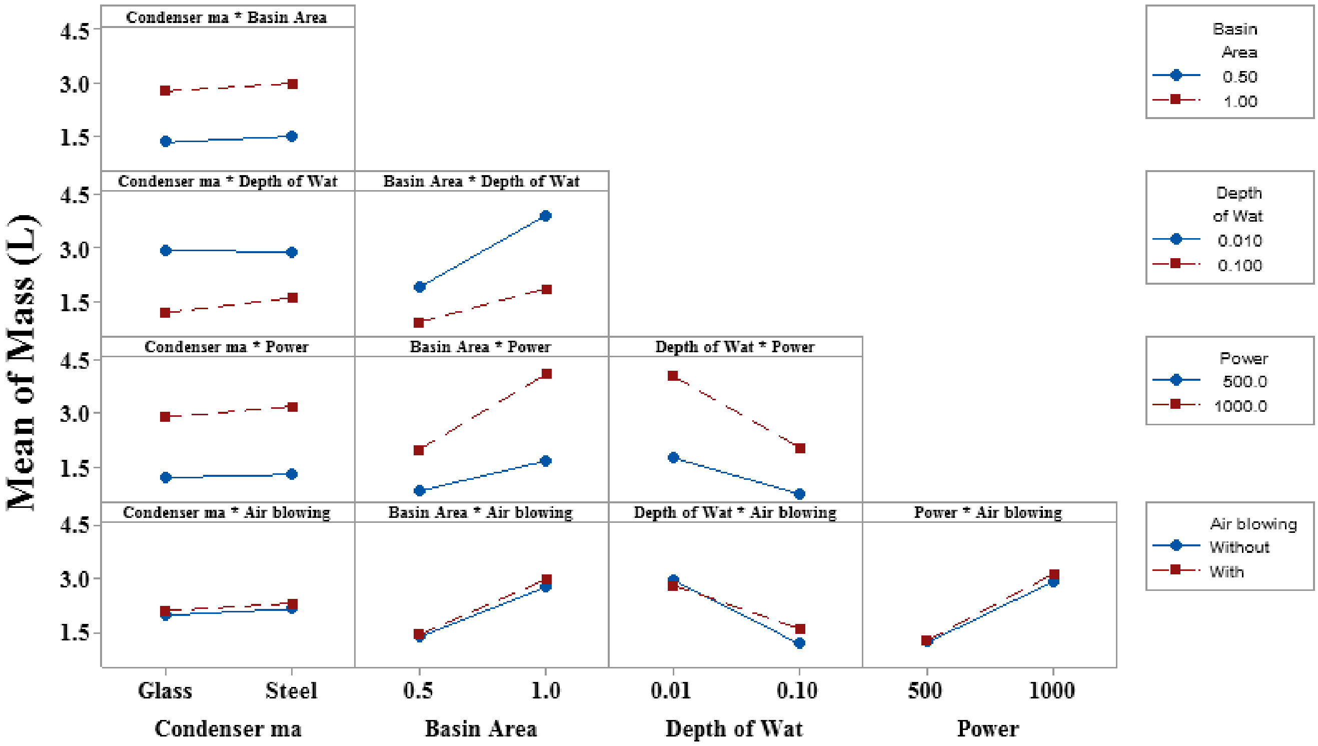

Mean of Tw (C)
Condenser material
Thickness of Condenser
Basin Area
Depth of Water
Condenser Area
Insulation Thickness
70
65
60
55
50
Glass
Steel
0.004
0.008
0.5
1.0
0.01
0.10
Basin area
2*Basin area
0.01
0.05
Insulation Material
Power
Air blowing
Ambient Temperature
Make-up system
Fiberglass
Wood
500
1000
Without
With
20
40
Without
With

(b)

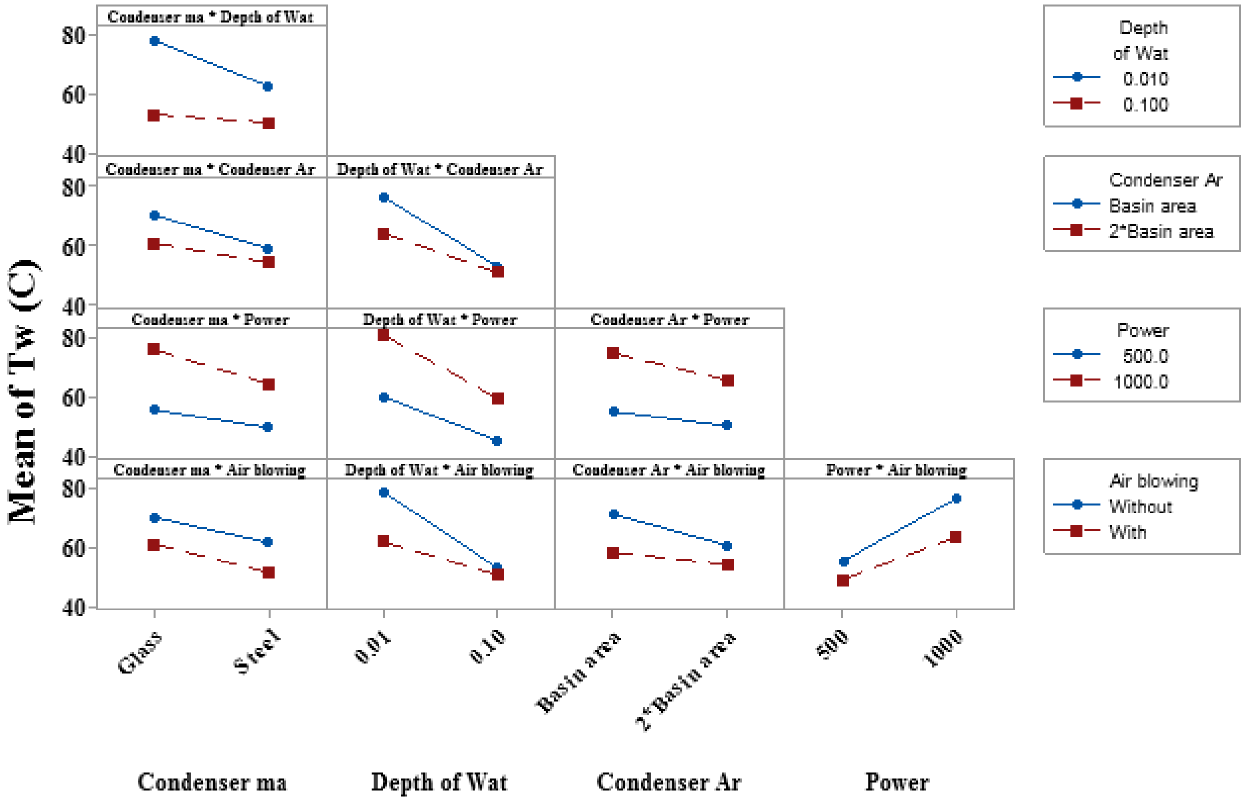


(C)

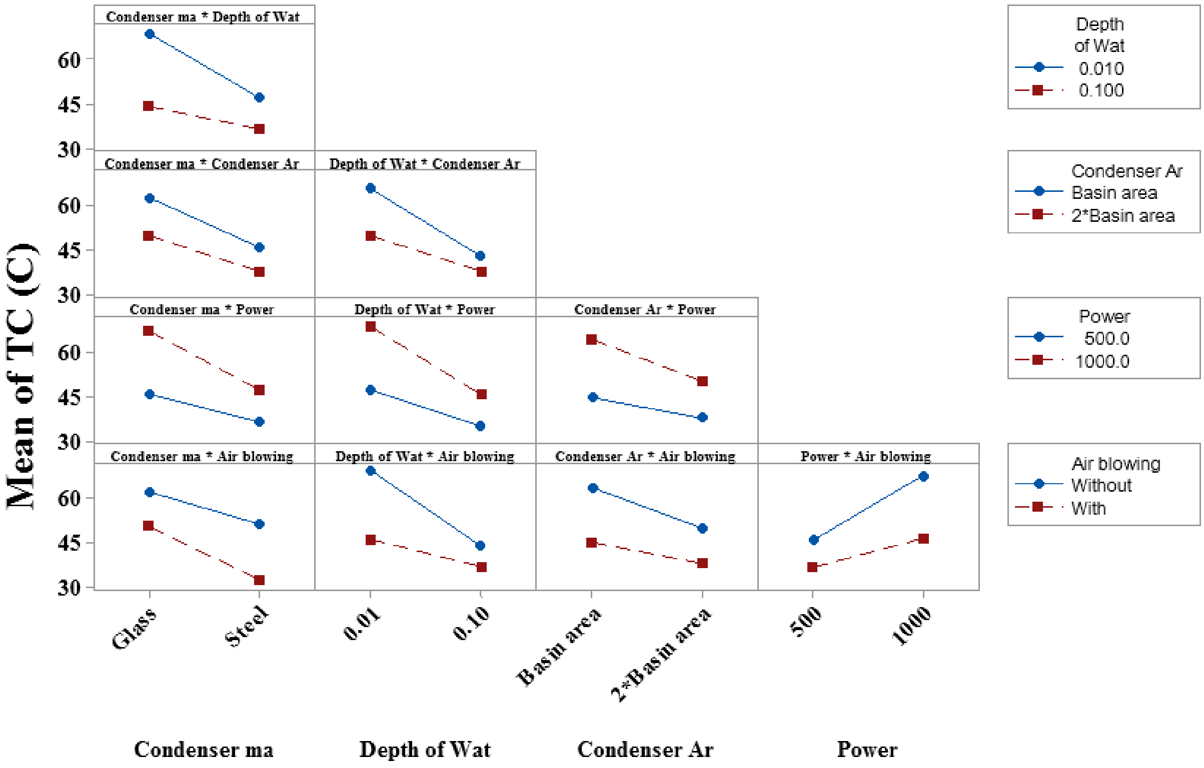
Figure 5. main effect factors on **(a)** mass output, **(b)** water temperature and **(c)** condenser cover temperature.


Mean of Mass (L)
Condenser ma * Basin Area
Condenser ma * Depth of Wat
Basin Area * Depth of Wat
Condenser ma * Power
Basin Area * Power
Depth of Wat * Power
Condenser ma * Air blowing
Basin Area * Air blowing
Depth of Wat * Air blowing
Power * Air blowing
4.5
3.0
1.5
Glass
Steel
Condenser ma
0.5
1.0
Basin Area
0.01
0.10
Depth of Wat
500
1000
Power
Basin Area
0.50
1.00
Depth of Wat
0.010
0.100
Power
500.0
1000.0
Air blowing
Without
With

(a)

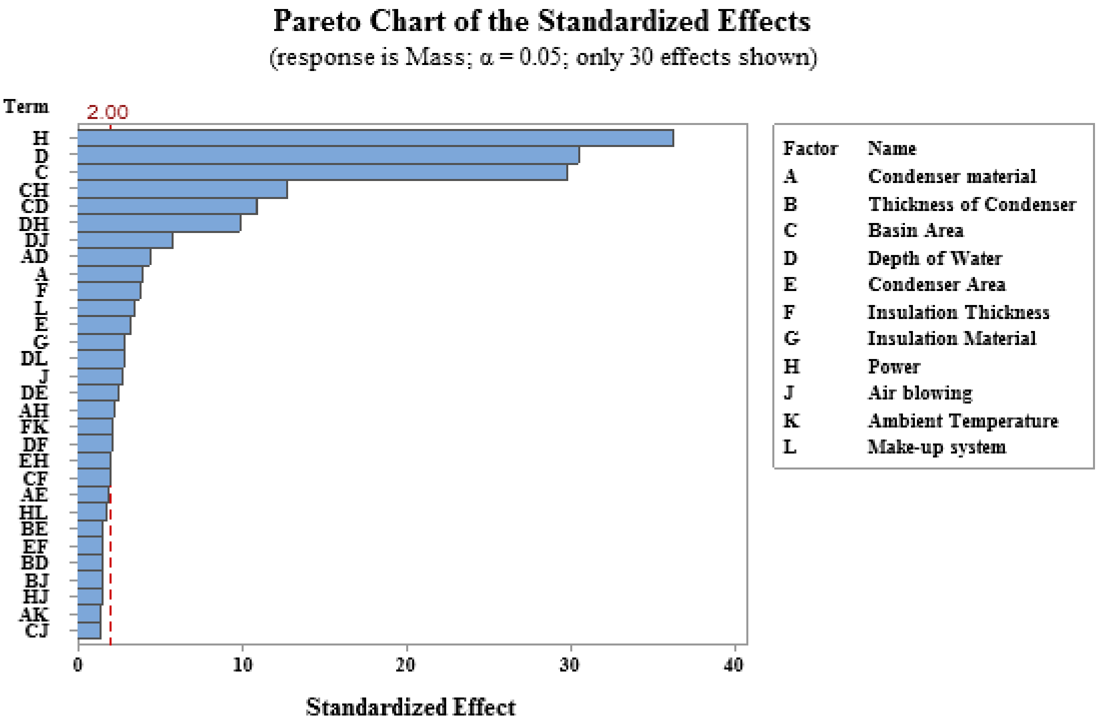

Mean of Tw (C)
Condenser ma * Depth of Wat
Condenser ma * Condenser Ar
Depth of Wat * Condenser Ar
Condenser ma * Power
Depth of Wat * Power
Condenser Ar * Power
Condenser ma * Air blowing
Depth of Wat * Air blowing
Condenser Ar * Air blowing
Power * Air blowing
80
60
40
Glass
Steel
0.01
0.10
Basin area
2*Basin area
500
1000
Condenser ma
Depth of Wat
Condenser Ar
Power
Depth of Wat
0.010
0.100
Condenser Ar
Basin area
2*Basin area
Power
500.0
1000.0
Air blowing
Without
With

(b)



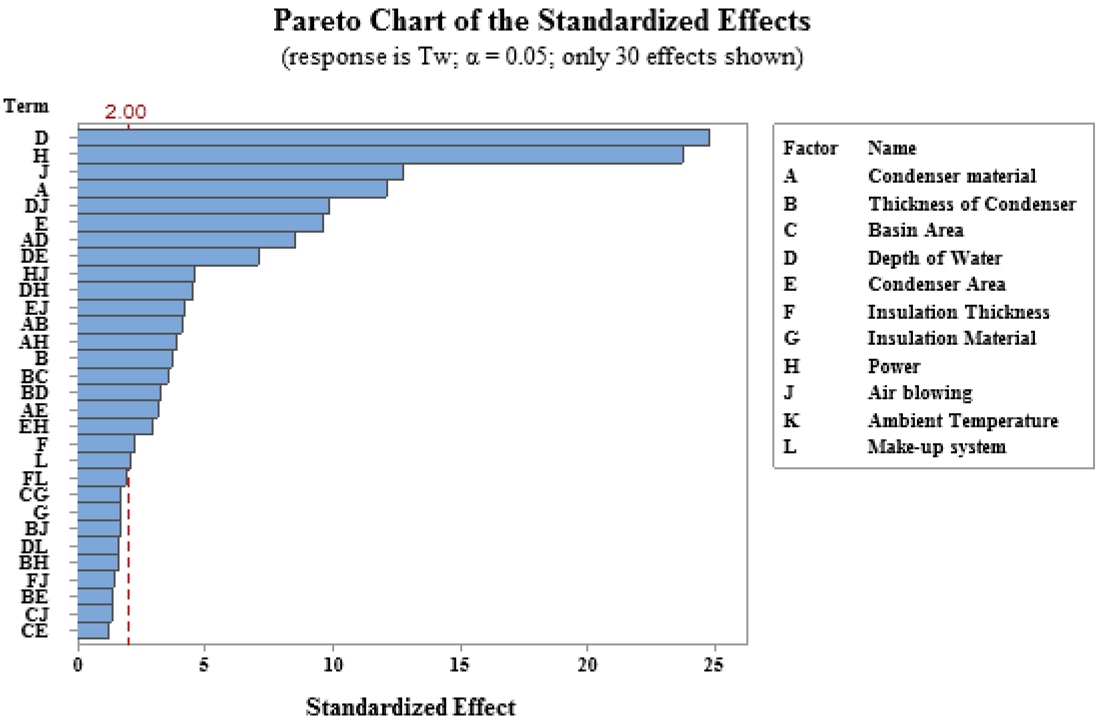
(c)

Figure 6. Interaction effect plot on **(a)** mass output, **(b)** water temperature and **(c)** condenser cover temperature.



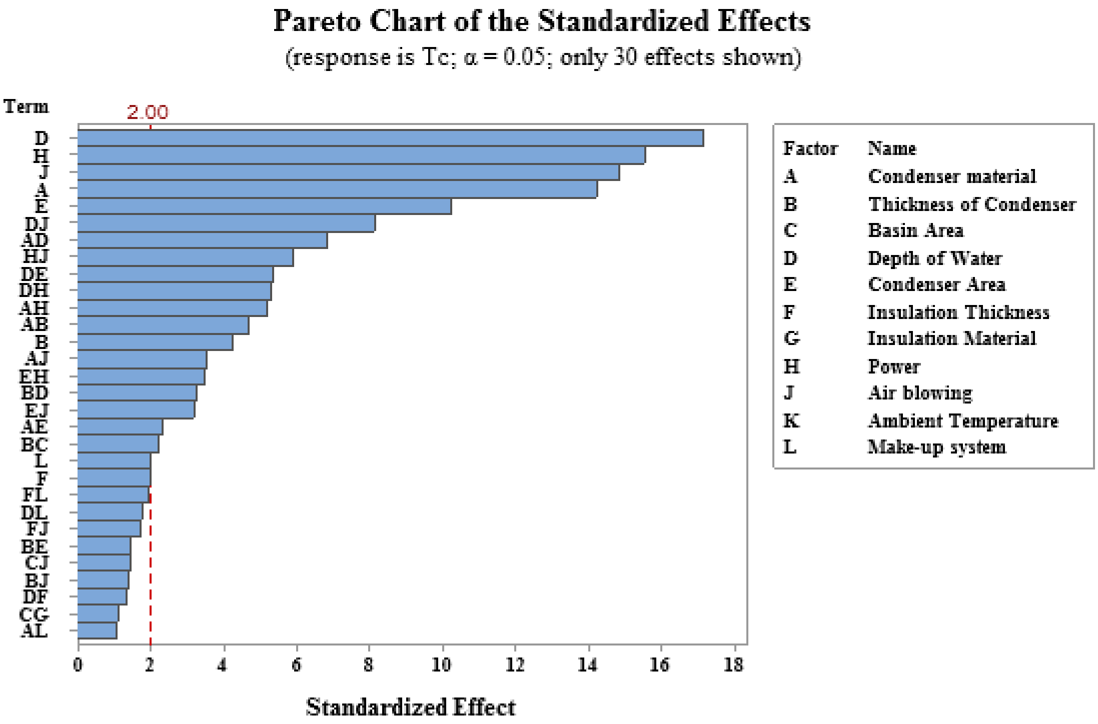
Pareto Chart of the Standardized Effects
(response is Mass; α = 0.05; only 30 effects shown)
Term
2.00
H
D
C
CH
CD
DH
DJ
AD
A
F
L
E
G
DL
J
DE
AH
FK
DF
EH
CF
AE
HL
BE
EF
BD
BJ
HJ
AK
CJ
0
10
20
30
40
Standardized Effect
Factor Name
A Condenser material
B Thickness of Condenser
C Basin Area
D Depth of Water
E Condenser Area
F Insulation Thickness
G Insulation Material
H Power
J Air blowing
K Ambient Temperature
L Make-up system

(a)



Pareto Chart of the Standardized Effects
(response is Tw; α = 0.05; only 30 effects shown)
Term
2.00
D
H
J
A
DJ
E
AD
DE
HJ
DH
EJ
AB
AH
B
BC
BD
AE
EH
F
L
FL
CG
G
BJ
DL
BH
FJ
BE
CJ
CE
0
5
10
15
20
25
Standardized Effect
Factor Name
A Condenser material
B Thickness of Condenser
C Basin Area
D Depth of Water
E Condenser Area
F Insulation Thickness
G Insulation Material
H Power
J Air blowing
K Ambient Temperature
L Make-up system

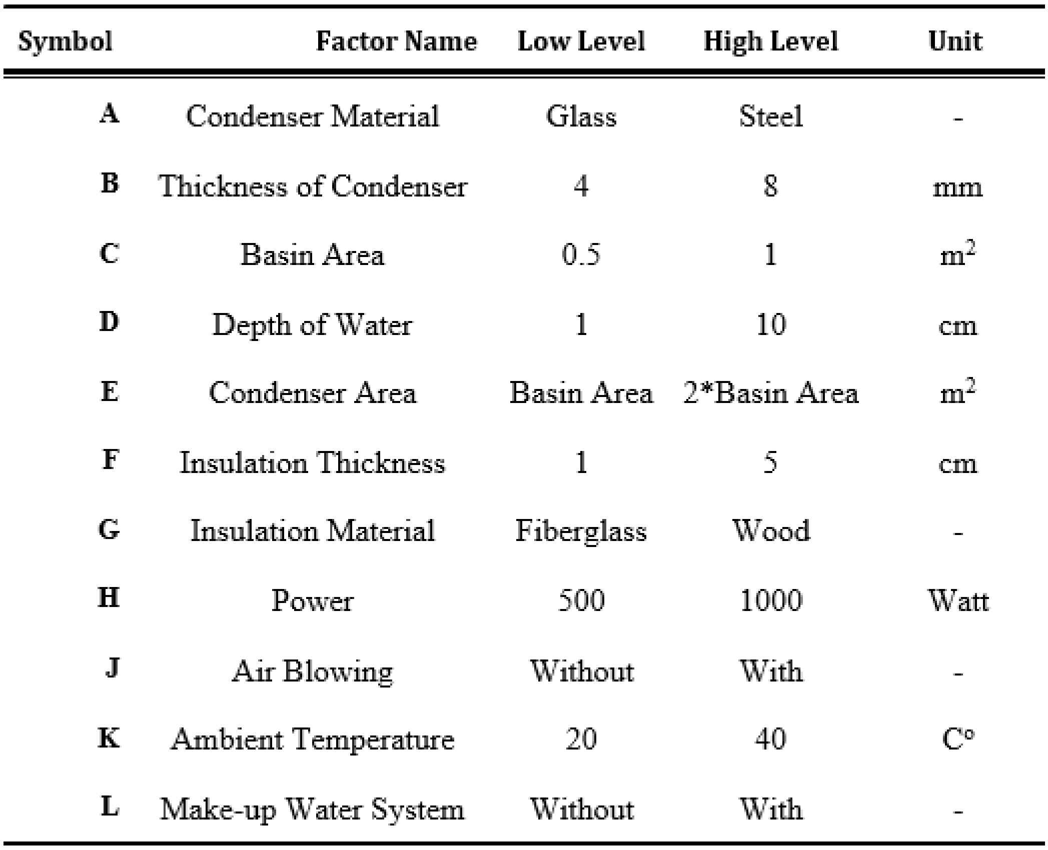
(b)



(c)

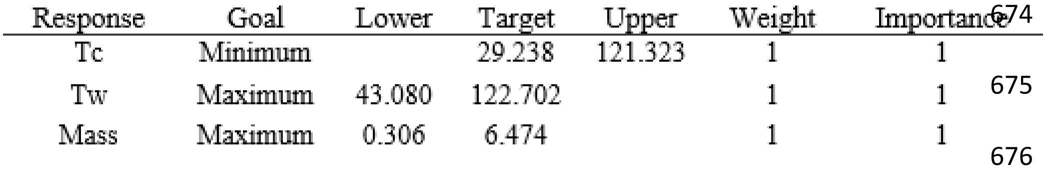
Figure 7. Pareto charts of the standardized effects for **(a)** mass output, **(b)** water temperature and **(c)** condenser cover temperature.

Table 1: Description of factor levels.



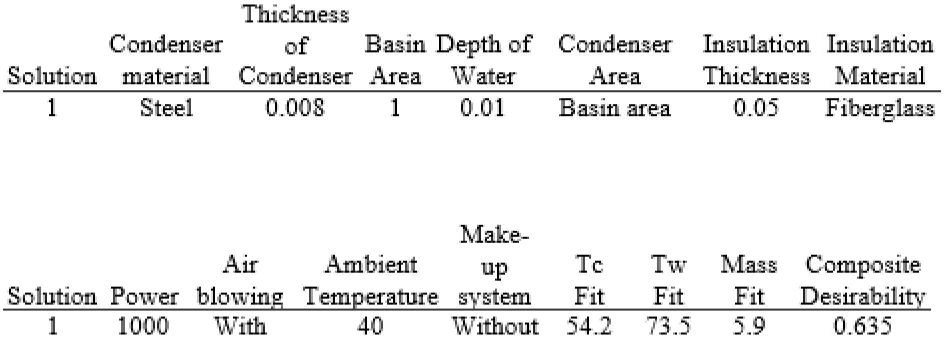
Symbol	Factor Name	Low Level	High Level	Unit
A	Condenser Material	Glass	Steel	-
B	Thickness of Condenser	4	8	mm
C	Basin Area	0.5	1	m^2
D	Depth of Water	1	10	cm
E	Condenser Area	Basin Area	2*Basin Area	m^2
F	Insulation Thickness	1	5	cm
G	Insulation Material	Fiberglass	Wood	-
H	Power	500	1000	Watt
J	Air Blowing	Without	With	-
K	Ambient Temperature	20	40	C°
L	Make-up Water System	Without	With	-

Table 2. Responses fit values



Response	Goal	Lower	Target	Upper	Weight	Importance
Tc	Minimum		29.238	121.323	1	1
Tw	Maximum	43.080	122.702		1	1
Mass	Maximum	0.306	6.474		1	1

Table 3. Values for optimal solar still design



Solution	Condenser material	Thickness of Condenser	Basin Area	Depth of Water	Condenser Area	Insulation Thickness	Insulation Material
1	Steel	0.008	1	0.01	Basin area	0.05	Fiberglass

Solution	Power	Air blowing	Ambient Temperature	Make-up system	Tc Fit	Tw Fit	Mass Fit	Composite Desirability
1	1000	With	40	Without	54.2	73.5	5.9	0.635