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PERFORMANCE & ANALYSIS AND OPTIMIZATION OF STEPPED TYPE SOLAR STILL

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ABSTRACT
As water shortage is becoming a major problem of national as well as international concern, desalination will increasingly be required to meet growing demands of fresh water. Desalination technologies have developed rapidly during the past several decades for desalting a variety of raw waters such as seawater, brackish ground water, industrial waste water etc.The present study aims to improve the solar still performance and to increase its distillate yield. So it is necessary to evaluate some important parameters affecting the system productivity. The effect of depth of water, glass cover thickness, Different depths of saline water over the basin (5 mm, 7.5 mm and 10 mm); different thicknesses of the glass cover (3.5 mm and 4 mm); are tested under the same climatic conditions. The study aims to introduce the applicability of a stepped type solar still to determine the various parameters that influence the performance of stepped type solar still. To vary the depth of water in the basin of stepped type solar still. To vary glass cover thickness of stepped type solar still. Presentation of the optimized results obtained after detailed analysis of the data generated for various configurations of solar stills.

Keywords: Depth of solar stil glass cover thickness enhancement of productivity etc.

I. INTRODUCTION
Man has needed and used energy at an increasing rate for his sustenance and well-being ever since he came on the earth a few million years ago. Primitive man required energy primarily in the form of food. He derived this by eating plants or animals, which he hunted. Subsequently he discovered fire and his energy needs increased as he started to make use of wood and other biomass to supply the energy needs for cooking as well as for keeping himself warm. With the passage of time, man started to cultivate land for agriculture. He added a new dimension to the use of energy by domesticating and training animals to work for him. With further demand for energy, man began to harness the wind for sailing ships and for driving windmills, and the force of falling water to turn water wheels. By this time, it would not be wrong to say that the sun was supplying all the energy needs of man either directly or indirectly and that man was using only renewable sources of energy.

The Industrial Revolution, which began with the discovery of the steam engine (AD1700), brought about a great many changes. For the first time, man began to use a new source of energy, viz. coal, in large quantities. A little later, the IC engine was invented (AD1870) and the other fossil fuels, oil and natural gas began to be used extensively. The fossil fuel era of using non-renewable sources had begun and energy was now available in a concentrated form. The invention of heat engines and the use of fossil fuels made energy portable and introduced the much-needed flexibility in the movements of a mankind. For the first time, man could get the power of a machine where he required it and was not restricted to a specific site like a fast running stream for running a water wheel or a windy hill for operating a windmill. This flexibility was enhanced with the discovery of electricity and the development of central power generating stations using either fossil fuels or water power.

A Solar Still is a device that produces clean, drinkable water from dirty water using the energy from the sun. This inexpensive device can easily be built using local materials. Presently, basin type solar still is the only device that is being used for water distillation applications although there are photovoltaic based devices for water purification. However leakage of water vapors through joints and glass sealings of solar stills was found to be major reason for their limited use. While basin type solar stills may be used for meeting individual requirements, they are not suitable for large distillation systems as may be required for a small village or a small

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industrial unit. Against this backdrop, research and development in the field of solar stills can be directed to obtain higher distillate yield of the required quality with maximum still efficiency by using advanced stepped type solar still. This is precisely what the proposed work is aimed at with the scope limited to the development of an efficient stepped type solar still with maximum distillate yield.

Objectives of the Present Study

Desalination of ground brackish water by solar powered systems is a practical and promising technology for producing potable water in the regions which suffers from water scarcity especially in arid areas. In remote and arid areas in India, the abundant solar radiation intensity along the year and the available brackish water resources are two favorable conditions for using the desalination solar technology to produce the fresh water, especially for domestic use. Based on these conditions, a small scale solar powered desalination system has been constructed and operated.

The present study aims to improve the solar still performance and to increase its distillate yield. So it is necessary to evaluate some important parameters affecting the system productivity. The effect of depth of water, glass cover thickness, shape of the absorber area and various enhancements provided on the distillate yield are to be evaluated. In the same time, the effects of the design and operational parameters on the solar desalination process were investigated. Different depths of saline water over the basin (5 mm, 7.5 mm and 10 mm); different thicknesses of the glass cover (3.5 mm and 4 mm) The study aims to introduce the applicability of a stepped type solar still to determine the following:

1. Critical review of the literature on stepped type solar still.
2. To distinguish various parameters that influence the performance of stepped type solar still.
3. Based on above parameters, fabrication of different configurations of stepped type solar still.
4. To vary the depth of water in the basin of stepped type solar still.
5. To vary glass cover thickness of stepped type solar still.
6. To provide different enhancements in the basin of stepped type solar still.
7. To develop a mathematical model to determine the convective heat transfer coefficient for various configurations of solar stills.
8. Presentation of the optimized results obtained after detailed analysis of the data generated for various configurations of solar stills.

Depending on the different readings obtained for various configurations of stepped type solar still; performance optimization will be done on the basis of following parameters:

1. Variation of convective, radiative and evaporative heat transfer coefficients for various configurations of the solar stills.
2. Variation of distillate yield with time of the day for various configurations of the solar stills.
3. Variation of still efficiency for various configurations of the solar stills.
4. Variation of distillate yield with wind velocity for various configurations of the solar stills.

The various factors affecting the performance of the solar still are solar intensity, wind velocity, ambient temperature, water surface and inner glass cover temperature difference, free surface area of water, absorber plate area, temperatures of inlet water, glass cover inclination, still orientation and depth of water. The solar intensity, wind velocity, ambient temperature cannot be controlled as they are meteorological parameters whereas the remaining parameters can be varied to enhance the productivity of the solar stills. By considering the various factors affecting the productivity of the solar still, various modifications are being made to enhance the productivity of the solar still.

II. EXPERIMENTAL SET UP

The experimental setup consisting of different types of solar stills mounted on an iron stand with a saline water storage tank is as shown in Fig 2.1

The relationship between the size of a solar still and its capacity depends upon its design and efficiency. On cloudy or rainy days, production stops so it is necessary to build a solar device to anticipate this handicap. Therefore, it is best to provide for a good storage facility to hold the distilled water produced. Because this still is quite small, it is designed so that water collected can be drained into bottles.

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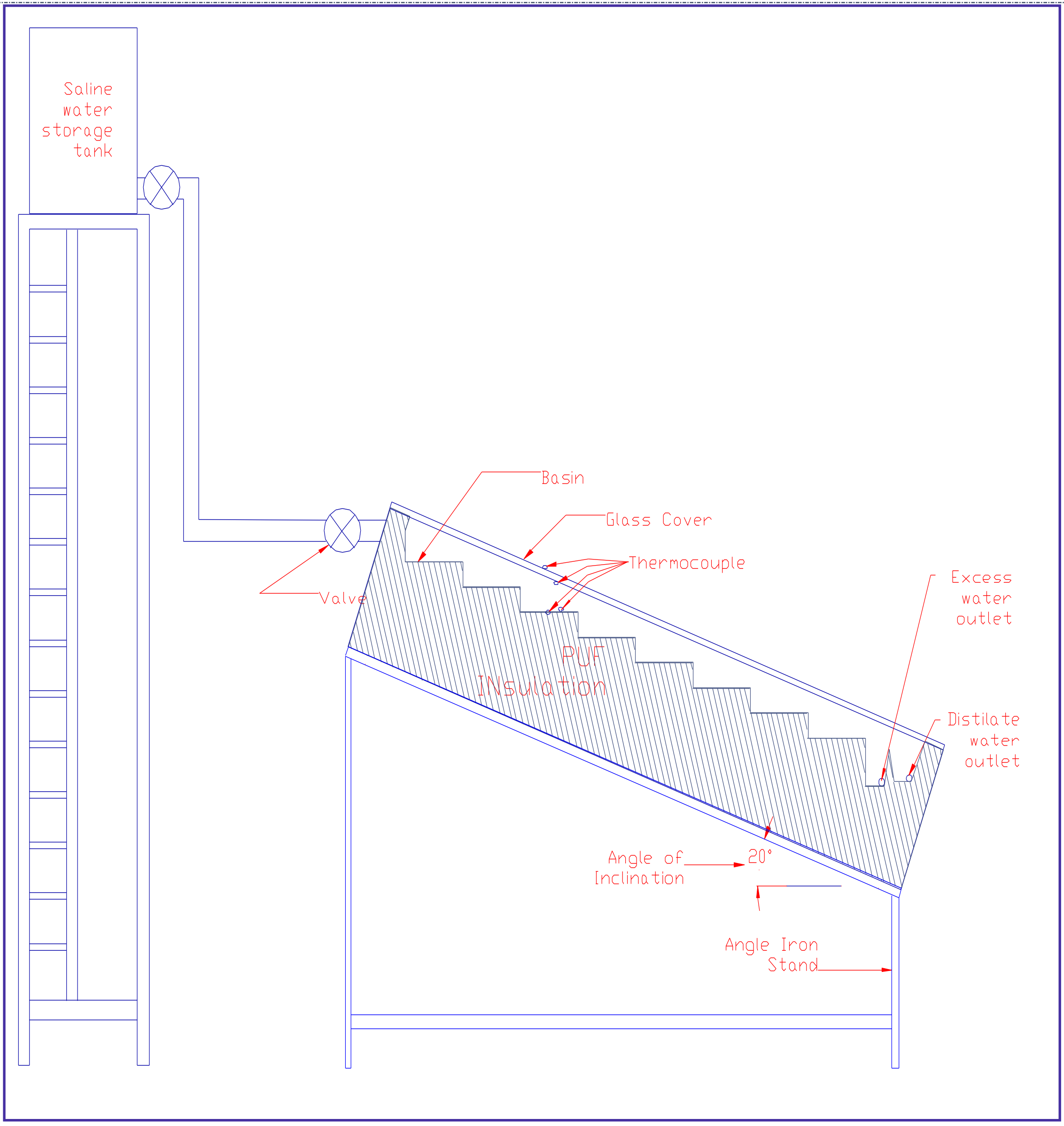

Fig.2.1: Schematic diagram of the experimental setup

A separate hole is drilled in the sidewall of the still to fix thermocouples to sense the temperatures of water in the basin, absorber plate temperature and inner glass cover temperature. The entire unit is placed on an angle iron stand inclined at an angle of 20.5^0equal to the latitude of Buldana to the horizontal. The still requires unobstructed sunshine from early morning to late afternoon. The solar still is oriented due south as the location lies in the northern hemisphere to receive maximum solar radiation throughout the year. This stepped type solar still system has been fabricated in the workshop of Rajarshi Shahu College of Engineering, Buldana. The experimental work was carried out on the roof of the non conventional energy systems laboratory, Mechanical Engineering Department of the institute. The experiments were performed during the months of January 2018 to April 2018 when the sky was clear i.e. on sunny days. The average sunshine at the selected location of Buldana was 4.88 kWh/m^2/day in January, 5.52 kWh/m^2/day in February, 6.3 kWh/m^2/day in March and 6.63 in April.

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Table 2.1: Experimental Setup

Sr. No.	Component	Description
1	Saline water storage tank	Volume - 1000 liters
2	Stepped type absorber plate	GI sheet – 22 gauge
3	Coating of absorber plate	Heat absorbent black dye
4	Design parameters to be varied	Depth of water, glass cover thickness, shape of absorber surface
5	Shapes to be provided to the absorber surface	Flat type basin
6	Metal box	Overall dimensions : 1067mm(L) x 686mm(W) x 228mm(H)
7	To compensate loss of water	Every half an hour

III. WORKING OF THE STILL

The stepped type solar still used in the present work has been provided with eight number of steps of size 620 mm (L) x 100 mm (W). The steps are filled with saline water one after another starting from the top and the excess water comes out from the excess water channel provided at the bottom. The excess water, if any is collected for reuse in the solar still. The average spacing between the saline water surface and the condensing glass cover is kept as 0.01m. When solar radiations fall on the glass cover, it gets absorbed by the black absorber plate. Due to this, the water contained in the steps begins to heat up and the moisture content of the air trapped between the water surface and the glass cover increases. When the water absorbs maximum solar radiations equal to the specific heat capacity of its mass, it is saturated and evaporation of water takes place. The basin also radiates energy in the infrared region, which was reflected back into the solar still by the glass cover, trapping the solar energy inside the solar still. The water vapors formed due to the evaporation of water are condensed at the inside of glass cover, as its temperature is less. The condensed water trickles down to the distillate collection trough provided at the bottom and is collected into a glass beaker by using a hosepipe, which is mounted at the side of the solar still.

As evaporation of water in the steps takes place, the saline water level in the solar still decreases. The distillate yield was measured every one hour during daylight from 10 am to 5 pm. The distillate yield during non-sunshine hours was collected daily in the morning at 9 am before the commencement of the experiment. To compensate the loss of water, for every half an hour, the makeup water was added to the solar still from the storage tank.

3.1 Data Recording System

The list of the instruments used for measuring different parameters of the stepped type solar still is given in Table 3.1

Table 3.1: Measuring Instruments

Sr. No.	Name of the instrument	Parameter to be measured
1	Iron constantan thermocouples	Temperature
2	Vane type digital anemometer	Wind velocity
3	Collecting vessel	Distillate yield

The alloy combination, polarity and measurement range for the thermocouples is as given in the Table 3.2

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Table 3.2: Thermocouples

Item	Specification
Type of thermocouple	J – Type Iron constantan thermocouple
Alloy of positive wire	Iron (100% Fe)
Alloy of positive wire	Constantan (55% Cu – 45% Ni)
Temperature range	0 – 750^{0}C

IV. OBSERVTIONS

Stepped Type Solar Stills with Varying Depths of Water

- Variation between the temperatures at different locations of solar stills A,B and C
- Variation of distillate yield with time of the day for solar still A,B and C

Stepped type solar stills with varying glass covers

- Variation between the temperatures at different locations of solar stills A and D
- Variation of productivity in stepped solar still with glass covers equal to 3.5 mm and 4 mm

Table 4.1: Temperature, distillate yield and wind velocity for solar stills

Date : 05/03/2018 **Time: 9:00 am**

Solar Still	T1 (Tb)	T2 (Tw)	T3 (Tgi)	T4 (Tgo)	T9 (Ta)	Y (ml)	Yact (ml)	V (m/s)
A	52	32	46	32	26	120	0	0.3
B	48	32	40	33	26	100	0	0.3
C	45	32	41	36	26	90	0	0.3
D	62	32	43	34	26	180	0	0.3

Time: 10:00 am

Solar Still	T1 (Tb)	T2 (Tw)	T3 (Tgi)	T4 (Tgo)	T9 (Ta)	Y (ml)	Yact (ml)	V (m/s)
A	58	57	55	49	30	180	60	0.7
B	53	49	47	39	30	150	50	0.7
C	44	43	42	36	30	130	40	0.7
D	57	54	52	45	30	270	90	0.7

Time: 11:00 am

Solar Still	T1 (Tb)	T2 (Tw)	T3 (Tgi)	T4 (Tgo)	T9 (Ta)	Y (ml)	Yact (ml)	V (m/s)
A	66	65	61	59	32	250	70	1.15
B	56	55	50	48	32	210	60	1.15
C	45	44	40	38	32	180	50	1.15
D	61	60	59	54	32	380	110	1.15

Time: 12:00 noon

Solar Still	T1 (Tb)	T2 (Tw)	T3 (Tgi)	T4 (Tgo)	T9 (Ta)	Y (ml)	Yact (ml)	V (m/s)
A	82	78	76	70	38	340	90	1.35
B	73	71	65	64	38	290	80	1.35
C	82	78	77	69	38	260	80	1.35

Stepped Type Solar Stills with Varying Glass Covers

The cover of the solar still must transmit solar radiation with minimum amount of absorption and reflection in the solar spectrum. It also acts as resistance to thermal radiation heat transfer from the basin to the atmosphere. The configuration and design parameters of solar stills are as given in the Table 4.2.

Table 4.2: Design parameters of solar stills

Sr. No.	Type of solar still	Depth of water in mm	Shape of absorber surface	Glass cover thickness in mm
1	A	5	Flat	4
2	B	5	Flat	3.5

V. THERMAL MODEL

A thermal model has been developed to determine the convective heat transfer for different Grashoff numbers in the solar distillation process. The model is based on simple regression analysis. Based on the experimental data obtained from the rigorous outdoor observations on various configurations of stepped type solar stills for summer climatic conditions, the values of C and n have been calculated. From these values, convective heat transfer coefficient is calculated based on the distillate yield obtained from the experimental observations. The percentage deviation between experimental and theoretical distillate yield is also obtained.

5.1 Thermo physical Properties of Water

The thermo physical properties of water [11] have been evaluated by using the following expressions wherein T_v represents an average [12] of the temperatures of evaporation and condensing surfaces and can be expressed as follows:

$$T_v = \frac{(T_w + T_{gi})}{2}$$

$$\rho = \frac{353.44}{(T_v + 273.15)}$$

$$\beta = \frac{1}{(T_v + 273.15)}$$

$$C_{pw} = 999.2 + 0.1434 \times T_v + 1.101 \times T_v^{-2} - 6.75 \times 10^{-8} \times T_v^3$$

$$K_a = 0.0244 + 0.7673 \times 10^{-4} \times T_v$$

$$\mu = 1.718 \times 10^{-5} + 4.620 \times 10^{-8} \times T_v$$

$$h_{fg} = 2324.6(1.0727 \times 10^3 - 1.0167 \times T_v + 1.4087 \times 10^{-4} \times T_v^2 - 5.1462 \times 10^{-6} \times T_v^3)$$

$$P_w = e^{(25.317 - 5144/T_w)}$$

$$P_{gi} = e^{(25.327 - 5144/T_{gi})}$$

5.2 Internal Heat Transfer Coefficients

Numerous empirical co-relations for heat and mass transfer coefficients to predict the hourly and daily distillate yield for different designs solar distillation units have been developed by various researchers. Most of these developed relations are based on simulation studies. Dunkle formulated a semi-empirical relation for internal heat and mass transfer in solar distillation units for the first time in 1961. He proposed the values of C = 0.075 and n = 1/3 on the basis of simulation studies for Gr > 3.2×10^5. However, this relation has the following

limitations:

- It is valid only for a mean operating temperature range of 50^0C and equivalent temperature difference of approximately 1^0C.
- It is independent of cavity volume i.e. the average distance between the condensing and evaporating surfaces.
- It holds good for heat flow upwards in horizontally enclosed air space.

Experiments were performed on all the eight different configurations of stepped type solar stills during the months of January 2018 to April 2018 for several days, but the observations presented in Tables 5.1-5.8 represent measured parameters on a typical day namely, 5th March, 2018.

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Table 5.1: Experimental observations for stepped type solar still A

Sr. No.	Time (hr)	Tw	Tv	Tgi	Ta	Yact
1	10:00 am	43	41	42	30	0.04
2	11:00 am	44	42	40	32	0.05
3	12:00 noon	78	77.5	77	38	0.08
4	1:00 pm	79	78.5	78	34	0.08
5	2:00 pm	64	63.5	63	32	0.11
6	3:00 pm	64	63	62	31	0.14
7	4:00 pm	62	60.5	59	29	0.12
8	5:00 pm	57	56.5	56	27	0.11

Table 5.2: Experimental observations for stepped type solar still B

Sr. No.	Time (hr)	Tw	Tv	Tgi	Ta	Yact
1	10:00 am	49	48	47	30	0.05
2	11:00 am	55	52.5	50	32	0.06
3	12:00 noon	71	68	65	38	0.08
4	1:00 pm	70	69.5	69	34	0.09
5	2:00 pm	71	69	70	32	0.12
6	3:00 pm	67	65	62	31	0.15
7	4:00 pm	63	62	61	29	0.14
8	5:00 pm	64	62.5	61	27	0.12

Table 5.3: Experimental observations for stepped type solar still C

Sr. No.	Time (hr)	Tw	Tv	Tgi	Ta	Yact
1	10:00 am	57	56	55	30	0.06
2	11:00 am	65	63	61	32	0.07
3	12:00 noon	78	77	76	38	0.09
4	1:00 pm	79	77.5	76	34	0.1
5	2:00 pm	67	66.5	66	32	0.14
6	3:00 pm	69	66.5	64	31	0.2
7	4:00 pm	59	58	57	29	0.15
8	5:00 pm	60	58	59	27	0.13

Table 5.4: Experimental observations for stepped type solar still D

Sr. No.	Time (hr)	Tw	Tv	Tgi	Ta	Yact
1	10:00 am	54	53	52	30	0.09
2	11:00 am	60	59.5	59	32	0.11
3	12:00 noon	82	80.5	79	38	0.13
4	1:00 pm	79	77.5	76	34	0.13
5	2:00 pm	69	68.5	68	32	0.16
6	3:00 pm	65	63	61	31	0.23
7	4:00 pm	59	58	57	29	0.19
8	5:00 pm	61	60.5	60	27	0.17

The governing equations applied to a stepped type solar still are discussed. Heat transfer occurs across the humid air inside the enclosure of the distillation unit by free convection which is caused by the action of buoyancy force due to density variation in the humid air. Density variation is caused by a temperature gradient in the fluid.

VI. RESULTS AND DISCUSSIONS

Results of the experiments and numerical calculations carried out for studying the performance of various configurations of stepped type solar stills are presented in this section. The distillate yield is the major factor in determining the performance of a solar still. The efforts of all the researchers working in this area are directed towards obtaining the maximum distillate yield for the given set of conditions.

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The experiments were conducted during the period of January 2018 to April 2018. All the solar stills were operated in the same climatic conditions to analyze the influence of the various configuration parameters on the distillate yield. Different variables are measured hourly such as Basin temperature (Tb), saline water temperature (Tw), inner glass cover temperature (Tgi), outer glass cover temperature (Tgo),ambient temperature (Ta), wind speed (V) and distillate yield (Yact).

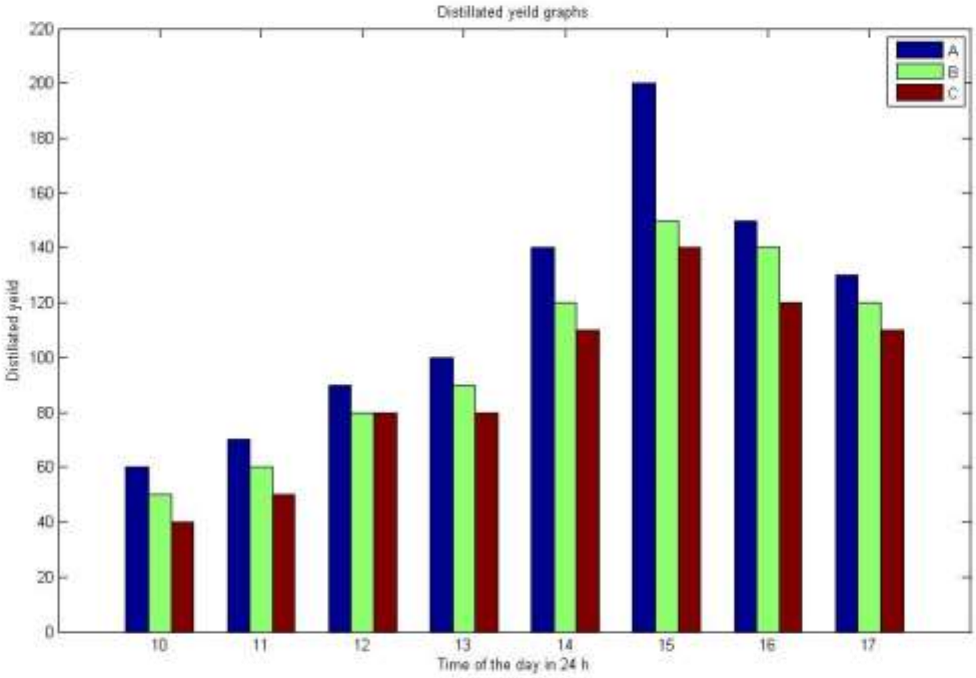

Fig.6.1: Distillate yield with time of the day for solar stills A, B and C

VII. CONCLUSION

Based on the results as discussed above; following conclusions can be drawn with respect to the various configurations of the solar stills:

The depth of water of 5 mm in solar still A produced the highest distillate yield of 1060 ml per day as compared to depth of waters of 7.5 mm and 10 mm in solar stills B and C. Solar still A was shown to have the highest thermal efficiency of about 21.42%. It can be concluded that the distillate yield of solar still decreases as the depth of water in the basin increases.

The glass cover thickness of 3.5 mm in solar still D produced the highest distillate yield of 1390 ml per day as compared to glass cover thickness of 4 mm in solar still A. Solar still D was shown to have the highest thermal efficiency of about 28.09%. It can be concluded that lesser the glass cover thickness; higher is the distillate yield.

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