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Study of thermal energy storage medium (Fly Ash) on the performance of a solar still

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ABSTRACT

The conventional solar still is modified by thermal energy storage material (Fly ash particles) to absorb the maximum amount of solar energy during shiny hours to increase the evaporation rate. In this work, fly ash is used effectively to store the thermal energy and also support the still to minimize the heat loss through bottom and side wall of the solar still. The fly ash is effectively used in the solar still to maintain the greater temperature difference between the glass inner surface and water by absorbing the excess amount solar energy during shiny hours. So, evaporation rate increases in the solar still. The quantity of the fly ash in the basin will influence the productivity of the still and other parameters like water temperature, glass surface temperature and vapour temperature etc. In this work, the experimental work has been conducted for various quantity of water and various depth of fly ash to find the optimum quantity of water and depth of fly ash in the basin. Finally, the performance of the modified solar still is compared with the conventional solar still under the same climate conditions. The productivity of the modified still is improved by 71 %.

Introduction

The world needs quality drinking water is increasing steadily with population growth and industrial revolution. So, Water purification using solar energy is suitable and economical for drinking water production from saline or waste water. Solar still is a device used for separation of pure water from waste water by using solar distillation process. It is the low cost device used for providing clean drinking water. Generally, solar still is made up of trapezoidal wooden box is covered by a glass cover, in which black painted steel or copper basin is kept inside with waste water to receive solar thermal energy. It is insulated with suitable material to minimize the heat loss through the sides and bottom of the solar still to utilize the solar thermal energy effectively. The waste water in the basin is heated by solar energy passing through the transparent glass cover and vapours flows upward from the hot water and condenses with inside surface of glass cover. The evaporation and condensation process takes place within the same chamber. The purified water is collected through a channel which is fitted along with the lower edge of the transparent cover.

The conventional solar still has a simple design, construction and low maintenance cost used in remote area too. The average productivity of solar still per square metre is limited to 2.5 l to 3 l per day. This low performance of the passive solar still creates interest among the researchers to improve the productivity by novel method. The evaporation rate of water vapour from the basin depends on the rate of condensation on inside surface of glass cover. So, it is very important to avoid the heat accumulation between the basin and glass inner surface for better productivity of solar still. It is possible by absorbing excess amount of heat energy during noon hours with help of thermal energy absorbing storage material. Many researchers are attempted to improve the performance of solar still with help of energy storage medium. Nafey et al.(1) conducted many experiments in active solar still by using varying the sizes of black gravels as storage medium for different quantity of waste water and improved the average still productivity per square metre from 0.5 to 1 litre per day. M.sakthivel et al.(2) conducted many experiments in active solar still by using varying the depth of (6mm) black granite gravels as storage medium for different quantity of waste water and improved the average still productivity per square metre nearly 0.9 litre per day for 30kg of water and 25 mm depth of black granite gravel. Hiteshpanchala D.K. Patela et al. (3) conducted experiments in active solar still by sandstones and marble pieces inside the still and generated 30% and 14% increment in potable water compared with the still without storage materials. Mona et al. (4) used paraffin wax and paraffin oil as the energy storage medium in solar still and achieved 15% more productivity than passive solar still. Bilal et al. (5) used black rubber material, black ink and black dye and improved the still productivity by 30% to 40%. Mona M Naim et al (6) used charcoal as heat absorber medium as well as wick and improved 15% still productivity over wick type stills. P.Rajendra Prasad et al (7) used a mixture of sodium silicate, hydrochloric acid and graphite powder in the solar still and improved solar productivity by 49%. Madani and Zaki (8) have used rubber mate for the improvement of the still productivity. Abdel-Rehima Zeinab and Lasheen Ashraf (9) used black materials, glass, rubber, black gravels to improve the solar still productivity.

In this work, heat accumulation between water and glass cover and continuation of still productivity during off sun shine hours are taken into main consideration. Fly ash is used

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as energy storage medium to receive and store the excess solar thermal energy during noon time. So, rate of evaporation is also improved.

Experimental Set Up

The conventional solar still was constructed using iron sheets (3mm thick) as shown in fig.1. The rectangular basin is made up of mild steel sheet which has a size of 1m x 0.5m x 0.1m and thickness is 0.002m. The inner surface of the basin is painted with black colour to absorb the maximum solar radiation. The still is covered by a glass which has a thickness of 0.004m and inclined to 13° to the horizontal. The gap between bottom and side walls of the basin is filled with glass wool (thermal conductivity 0.0038W/mK) of 45mm thickness. Further the side walls are insulated by thermo cool of 6 mm thickness.

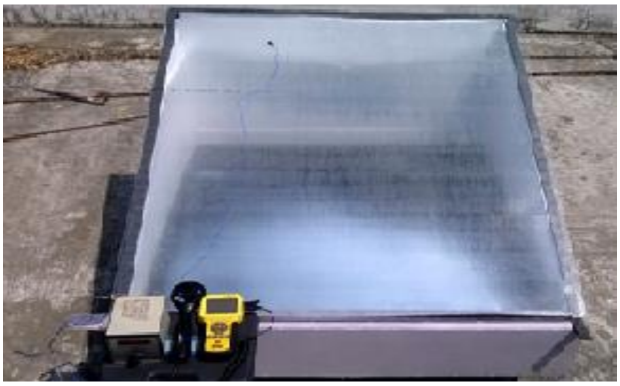


Fig 1. Photographic view of Experimental set up of solar still.

In this experiments, two identical conventional single slope solar still with same basin size were constructed as shown in fig.2 .The experiments were carried out at Dharmapuri (13°5´2´´N, 80°16´12´´E), Tamil Nadu, India. The still without fly ash is shown on right side and modified solar still with fly ash particles as energy storage medium in the basin is shown on left side.

A Saline water storage tank is connected to solar still through thermally insulated supply port and a float valve. The float valve is used to maintain the water level in the basin. A calibrated flask is used to collect the condensed water through aluminium channel which is attached to lower end of the glass cover and one valve is placed at the bottom of the solar still to drain the saline water. The solar still is placed in south direction to receive the maximum solar radiation. J-type thermocouples are connected to various parts of solar still to measure the temperatures of basin, water vapour, air space, glass inside, ambient temperatures. The solar radiation is measured by using solarimeter with accuracy ±1W/m^2.

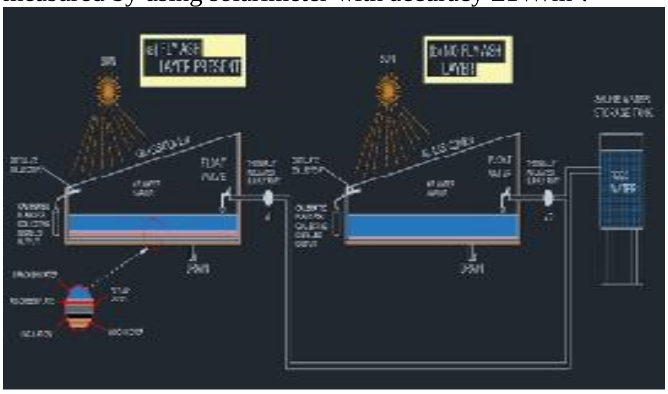


Fig 2.Schematic diagram of modified solar still.

Fly Ash Particles

The improvement is much needed in energy storage devices. The development of thermal energy storage material plays a vital role in solar still productivity. An attempt has been made to construct an energy efficient solar still with fly ash particles which is used to absorb large amount of solar radiation during shiny hours. In this study, coal fly ash was taken from the Mettur thermal power station, Tamilnadu, India. The overall chemical composition of the fly ash is tabulated in table-1 and few tests also carried out in fly ash and the results are listed below.

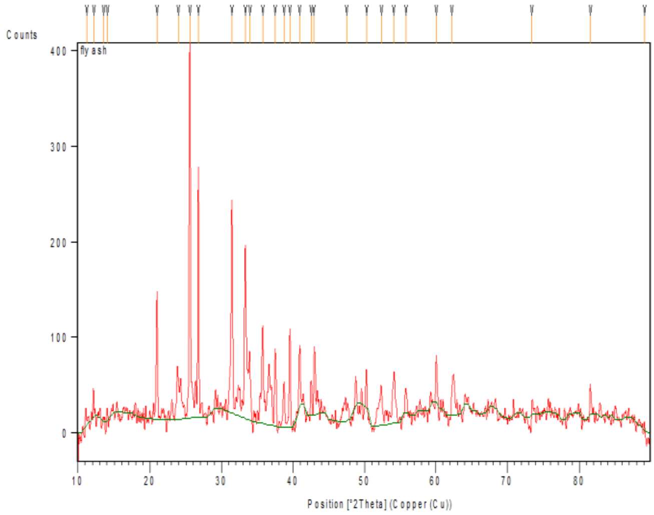
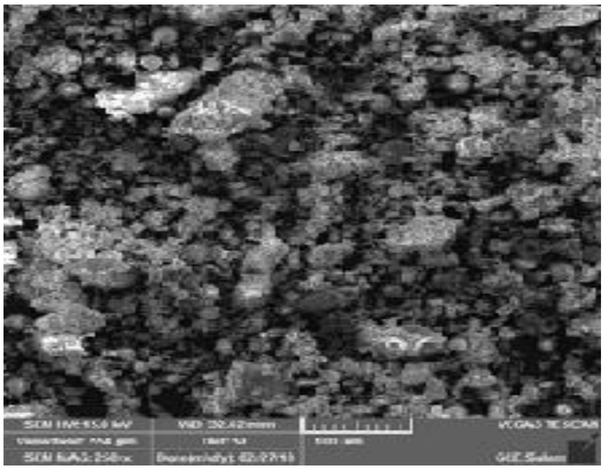
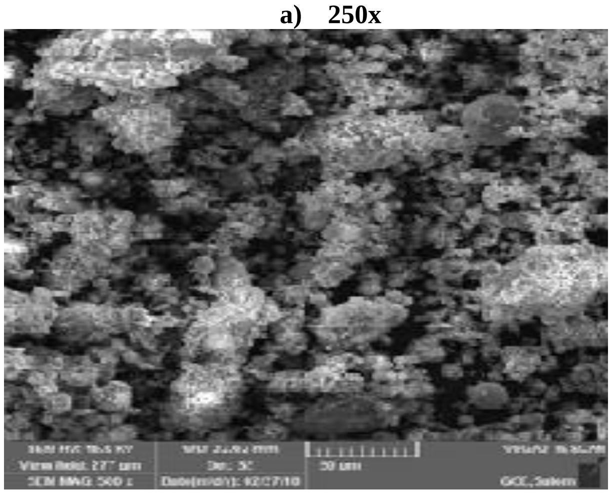


Fig 3. XRD analysis.

Powder Characterization



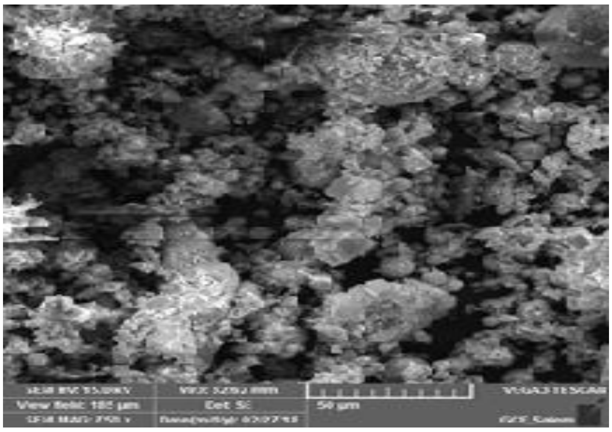
a) 250x



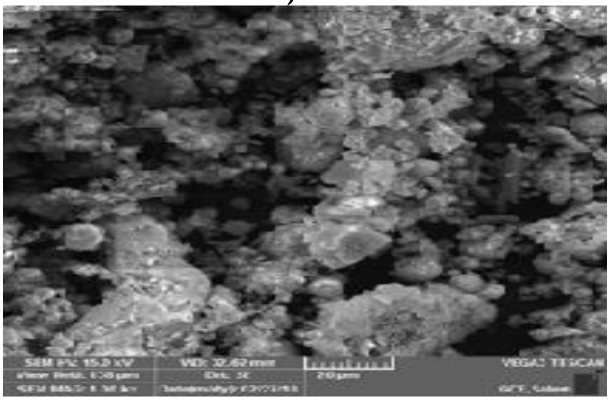
b) 500x

Table 1. Chemical composition of FLY ASH

Material	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	Na_2O	K_2O	*Others*
Percentage	59.93	19.66	3.33	1.12	2.82	0.34	0.22	*1.56*



c) 750 x



d) 1000 x

Fig 4.SEM Analysis of Fly Ash at a) 250 b) 500 c) 750 and d) 1000 magnification

The SEM images show the availability of pores in the fly ash particles and presence of Sio_2 which inhibits the thermal conductivity. The thermal diffusivity is directly dependent on specific heat and thermal conductivity. The fine powdered particles exhibit the lower thermal expansion, which increases the specific heat carrying capacity. Fly ash particles contain Sio_2 which also prevents the heat conduction. So, fly ash particles exhibit higher specific heat capacity. The presence of SiO_2 confirmed by XRD analysis and further validated by EDS analysis

Experimental Results and Discussion

The experiments were conducted in conventional single basin and single slope solar still to find the optimum depth of saline water in the basin and optimum time for maximum still productivity. All temperatures are recorded between 9.30am to 6.30pm. Then the experiments were conducted under the same climate conditions with various quantity of fly ash in the modified solar still to find the optimum quantity of fly ash for better still productivity.

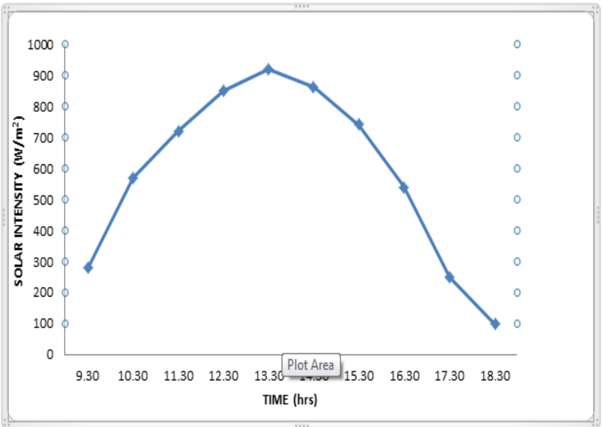


Fig 5. Solar intensity Vs Time.

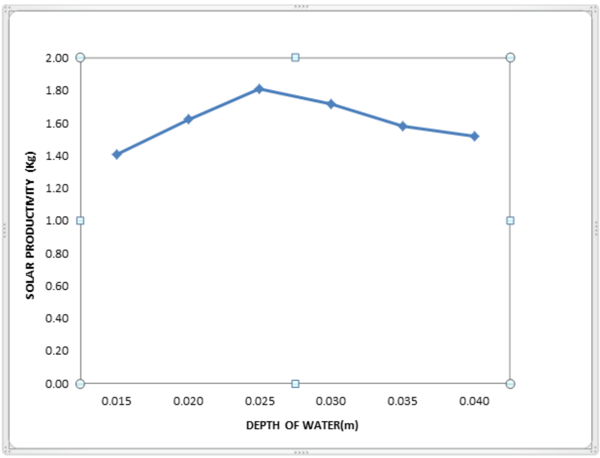


Fig 6. Solar productivity Vs Depth of water.

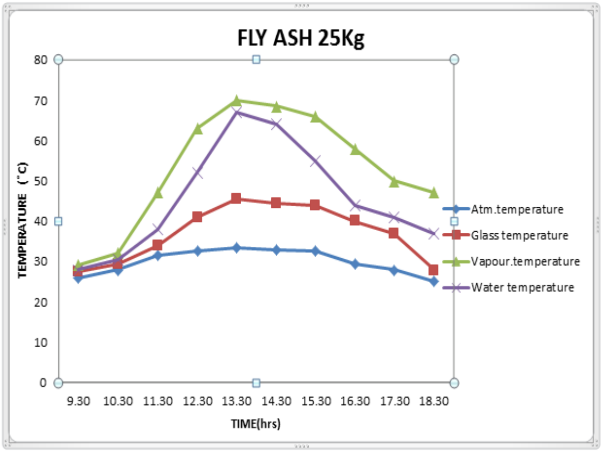


Fig 7. Temperature Vs Time.

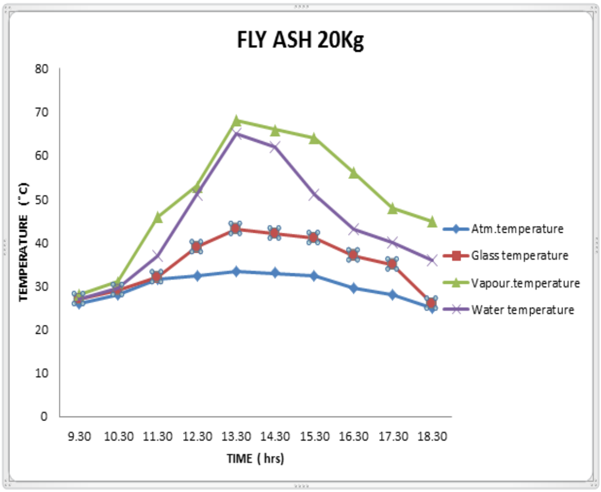


Fig 8. Temperature Vs Time

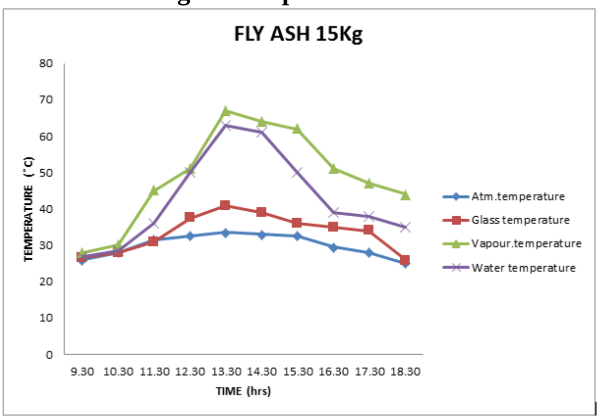


Fig 9 . Temperature Vs Time.

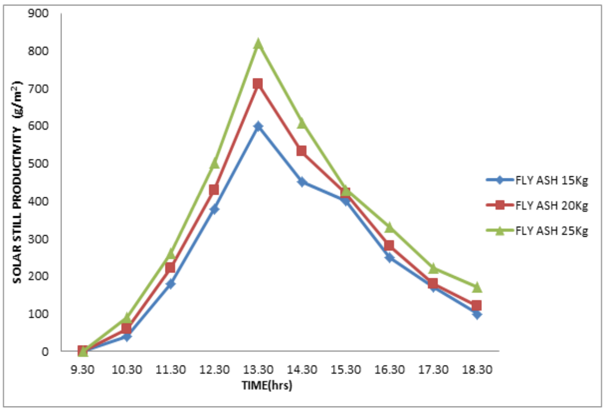


Fig 10 . Still productivity Vs Time.

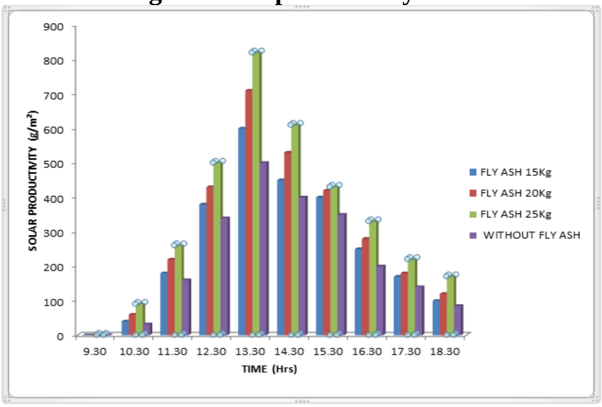


Fig .11.Comparison of various depth of fly ash with conventional still

Initially, the experiments were conducted in conventional solar still from 9.30am to 6.30pm during the month of May 2018 and found that the maximum solar intensity was received at 1.30pm and minimum received at 6.30pm as shown in fig.5. In this study, the experiments were conducted again in the conventional solar still to get the optimum value of water quantity by varying the quantity of saline water from 15mm to 40mm depth in the basin which has 0.5m2 area and found that the maximum still productivity is 1.80kg for 25mm of water depth in the basin and minimum yield at 15mm depth of water as shown in fig.6. Fig.7 shows clearly that the variation of different temperatures during day time for 25kg of fly ash from 9.30am to 6.30pm. The maximum water temperature is 67.5°C and vapour temperature is 70°C were observed at 1.30pm. The maximum ambient temperature is 32.5°C and maximum glass temperature is 45°C were also observed at 1.30pm. Fig.8 and 9 Shows the variation of different temperatures with time for 20kg and 15kg of fly ash, the graph illustrates that all temperatures are decreasing with reducing the quantity of fly ash in the basin. Fig .10 depicts that maximum solar productivity occurs while using 25kg of fly ash in the basin and minimum productivity occurs while using 15kg of fly ash. Fig .11 illustrates that yield increases with fly ash quantity compared to conventional solar still at all times.

Conclusion

In this study, the following conclusions are made

The conventional single basin single slope solar still was constructed, tested during day time and found that maximum still productivity occurs at 1.30pm for 25kg of saline water while using 25kg of fly ash in the basin. So, it can be concluded that the greater temperature difference maintained between glass inner surface and water while using 25kg of fly ash because of maximum absorption of solar energy. This study describes that fly ash particles are acted as good thermal energy storage medium effectively because it has low thermal conductivity and high heat capacity. So, heat accumulation between water and glass cover is prevented to get the maximum still productivity during day time.

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