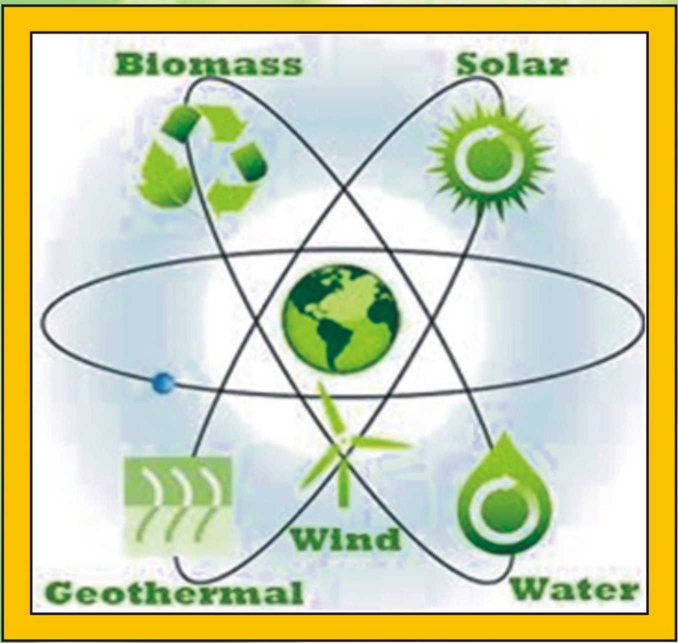
Compendium of Lectures



Renewable Energy for Sustainable Agriculture and Environmental Protection

March 8-10, 2021

Organised By:

Swami Keshwanand Rajasthan Agricultural University, Bikaner

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On

Renewable Energy for Sustainable Agriculture and Environmental Protection

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Organised by:

Department of Agri. Engineering, COA, SKRAU, Bikaner

and

Institute of Agri Business Management, SKRAU, Bikaner

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National Agricultural Higher Education Project (NAHEP) - ICAR

Solar Desalination: An approach for water purification

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Introduction

Water is a basic necessity of man along with food and air; the importance of supplying hygienic potable/fresh water (less than 500 ppm of salt) can hardly be over stressed. The man has been dependent on rivers, lakes and underground water reservoirs for fresh water requirements in domestic life, agriculture and industry. However, use of water from such sources is not always possible or desirable on account of the presence of large amount of salts and harmful organisms. The impact of many diseases afflicting mankind can be drastically reduced if fresh hygienic water is provided for drinking. But there are still countries in the world today where large amounts of the population are lacking fresh drinking water. As far as drinking water is concerned, it is scarcely available in western arid region of India and people depend on rain water collected from rooftop, which is too little to meet their drinking water demand. The impact of waterborne infectious diseases afflicting mankind can be drastically reduced if fresh hygienic water is provided for drinking. Generally in summer season, villagers travel many miles in search of fresh water. It is observed that at least one or two family members are always busy in bringing fresh water from distant sources. The worst conditions are generated if the resources of water are not available and villagers are forced to take highly saline underground water containing nitrate and fluorides or contaminated with pathogenic microbes pond water. Fortunately, India is blessed with abundant solar radiation. In arid part of Rajasthan, India solar irradiations are available in abundance and almost 300 clear sky days are observed. Amount of solar irradiation received in the region is about 7600–8000 MJm^{-2} per annum, whereas in semi-arid region it is about 7200–7600 MJm^{-2} per annum and in hilly areas it is about 6000 MJm^{-2} per annum. The conventional desalination technologies like multi stage flash, multiple effect, vapor compression, iron exchange, reverse osmosis, electro dialysis are expensive for the production of small amount of fresh water, also use of conventional energy sources has a negative impact on the environment. Solar distillation provides partially support humanity's needs for fresh water with free energy, simple technology and clean environment. Therefore, solar distillation seems to be a good substitute for conventional methods. The distillate output of solar still is to be mixed with the available saline water in appropriate proportion to make it drinkable. In fact as much as 20 litres/day of potable water (150 ppm TDS) can be made available in a day from raw water containing 300 ppm TDS by installing a solar still of capacity 10 litres/day. Solar distillation has been in practice for a long time. Solar distillation is carried out in solar still. The basin-type solar still is in the most advanced stage of development.

Metallic type solar desalination devices

Low glass roof type solar stills were developed in seventies for desalination of brackish water. These solar stills were further improved with proper slope in distillation channel, supporting truss for ridge, windows for cleaning on two sides, better sealing and incorporation of a system to mitigate problems of algae and scale formations. Thermal efficiency of such stills was found to range from 20 to 34% from winter to summer with productivity ranging from 1.0 to 3.3 litres m^{-2} day^{-1}. On the other hand in step basin tilted type solar stills having capacity to produce 3 to 3.5 litres m^{-2} day^{-1} distilled water throughout the year indicating that the distillate output of this novel still is not much affected by the seasons (Fig. 1). The design of double sloped solar still was optimised by considering different designs and the effects of climatic and operational parameters on the performance of solar still and to solve the operational problems by pre-treating the brackish water to prevent scaling and algae growth. However, it was found that the productivity of the double-sloped solar stills was only 1-2 litres m^{-2} day^{-1} during winter months compared to 3-3.5 litres m^{-2} day^{-1} in summer. The productivity of single sloped solar still was increased during winter by 27% with the use of additional reflector in single sloped solar still.

Figure 1: Step basin tilted type solar stills

Further four similar metallic solar desalination devices (absorber area 1.13 m^2) developed was continued with water having salt concentration 0.0, 2.5, 5.0, and 7.5 g/L and found to provide average distillate output as 1.030, 0.974, 0.973 and 0.966 litres m^{-2} day^{-1}, respectively. Electrical conductivity of raw saline water having salt 2.5, 5.0 and 7.5 gL^{-1} was 15.09, 17.11, 17.38 m mhos that was reduced to 1.84, 3.85, 4.82 m mhos in commercial RO plant while it was 0.14, 0.44, 0.64 m mhos in solar desalination devices respectively.

Figure 2: Metallic type solar stills

Basin type desalination device

Solar desalination devices made of cement-concrete, cement hollow block**,** vermiculite-cement, brick and stone masonry and plastered with cement have been designed, developed and constructed. These are basin type solar stills and made of different types of building/construction materials. The condensing cover of 3.5 mm thickness is made of plane glass which has been placed over the basin of solar still. The inclination of condensing cover for solar still is 20^o from the horizontal. The absorber area of each device is 4.2 m^2. The bottom surface of the still was painted with epoxy enamel black to have high absorptivity of solar radiation and resistance to salt and heat. The longer dimension of the device is in the east west direction so as to collect more solar radiation. The output from the solar desalination unit is collected into two distillate channels provided at lower side and is taken out through a pipe into a cylinder (Fig.3).

Figure 3: Solar desalination devices made of vermiculite-cement plastered material

Fig.4 and Fig. 5 shows the instantaneous distillate yield of the cement concrete hollow block**,** stone masonry, cement-concrete, brick masonary and vermiculite-cementbasin type solar still in the summer (May 2017) and winter (December 2017) month. The distillate yield was measured witha measuring jar at sixty minute intervals from 8.00 AM to 6.00 PM including day and night condensation. It was observed that inside temperature increasedas the solar intensity increased and hence rate of heat utilization for heating thewater was more at noon time and accordingly higher evaporation was observed after noon hours and then rate of condensation increased than noon time assolar intensity decreased.It wasobserved that maximum distillation rate obtained between 4 PM to 5 PM which was highest as 200 ml in all the basin type solar stills. In the summer month of May 2017, the total cumulative amount of daily productivity obtained by the hollow block walled was 8065 ml day^{-1} including day and night condensation, while the productivity of the stone masonry type solar still was 8117 ml day^{-1}. With the different building material, productitity increased to 8230 ml day^{-1} in cement-concrete walled and 8340 ml day^{-1} in the case of still with brick and stone masonry walls. Finally, with walls with vermiculite-cement blocks, productivity increased to 8540 ml day^{-1} which was 475 ml day^{-1} more than the still with cement concrete hollow block**,** and provided the highest distillate output because of better insulation and reduced heat loss that is why it gave better performance over other units. Variation of total distillate output/day with respect to different type of basin still is shown in Fig. 6. As expected, performance of the stills increases when the insulating material of thebase changes from different building materials with salt encrustation.

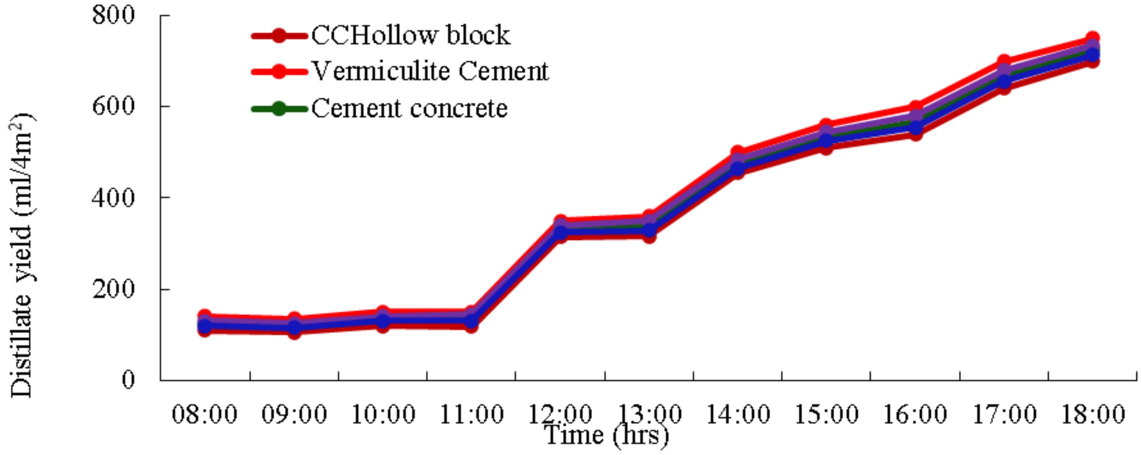

Figure 4: Variation of distillate yield for different basin type of solar still during May 2017

In the winter month of Decemer 2017, the total cumulative amount of daily productivityobtained by the hollow blockwalled was 7029 ml day^{-1} including day and night condensation, while the productivity of the stone masonry type solar still was 7173 ml day^{-1}. With the different building material, productitity increased to 7285 ml day^{-1} in cement-concrete walled and 7395 ml day^{-1} in the case of still with brick and stone masonry walls. Finally, with walls with vermiculite-cement blocks, productivity increased to 7595 ml day^{-1} which was 566 ml day^{-1} more than the still with cement concrete hollow block**,** and provided the highest distillate output because of better insulation and reduced heat loss that is why it gave better performance over other units. Variation of total distillate output/day with respect to different types of basin still is shown in Fig. 5.

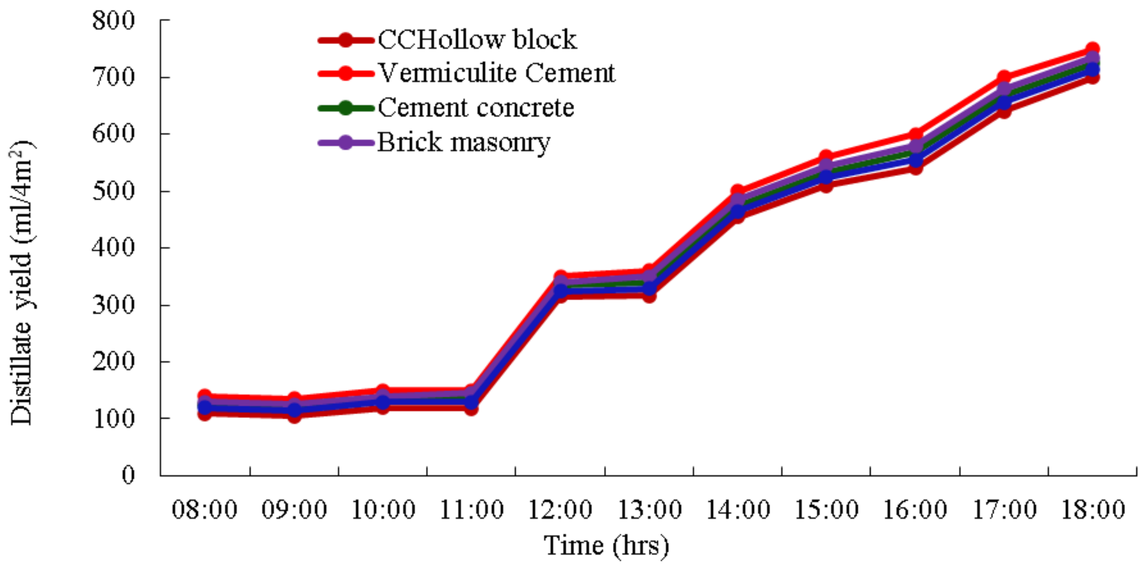

Figure 5: Variation of distillate yield for different basin type of solar still during December 2017

The performance evaluation of the devices made of hollow block, stone masonry, cement-concrete, brick masonary and vermiculite-cement basin type solar stills for which the disttllate efficiencies were 24.61%, 28.21%, 28.55%, 29.54% and 30.25% and system efficiencies were found 28.3%, 32.7%, 32.8%, 33.6% and 34.5%, respectively. A comparison between conventional RO plant and desalination units made of building materials was also done using highly saline and the performance of such units was found to be better than that of conventional RO plant. Electrical concductivity (EC)of raw saline water having salt varying from 15.1 mmhos to 17.38 mmhos that was reduced to 1.84 mmhos to 4.82 mmhos in commercial RO plant while it varied from 0.14 mmhos to 0.64 mmhos in solar desalination devives respectively.

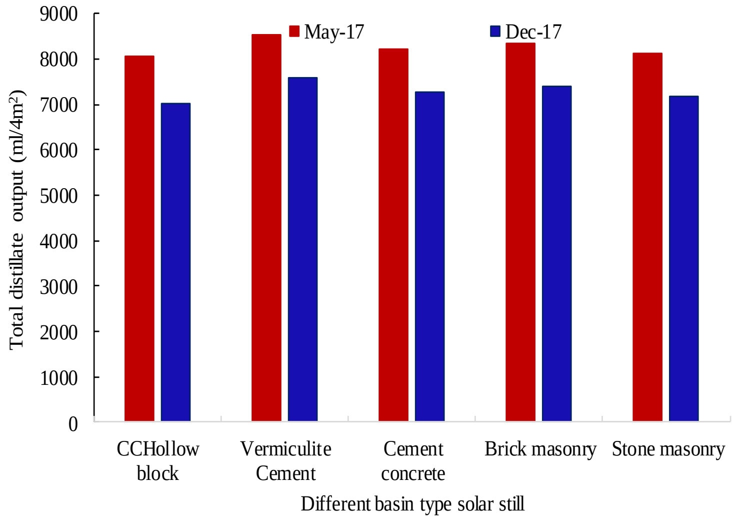

Figure 6: Total distillate output including night for various basin type solar still

Parabolic concentrating solar thermal desalination device

Solar desalination units made of building materials overcome the problems of corrosion but salt scaling and algae problems still exist. All metallic solar stills whether multi step basin or single basin are prone to corrosion, salt scaling and algae problem and have less life. To overcome these problems a concentrator-based distillation device was developed at ICAR-Central Arid Zone Research Institute, Jodhpur, India.

A parabolic concentrating solar thermal desalination device was designed and fabricated during the year 2019. The experimental device comprises a solar parabolic concentrator (SK -14 type) unit with a dish diameter 2.60 m and a performance of up to 700 Watts. The net power of the concentrator is approximately 600 watts in good sunshine hours and the average stagnation temperature at the bottom of the vessel of absorber surface is around 350°C, which is sufficient for boiling of water and steam generation. The number of reflector sheets varies from 24 to 36 in different designs manufactured by different manufacturers. Polished, anodized hardened aluminium sheets are used as reflectors. The system has been designed and fabricated in such a way that it could enable the combined production of distilled as well as hot water. The parabolic concentrating solar desalination device consists of a parabolic dish concentrator, evaporating vessel, condensing unit with glass tube, stand and distillate jar. The parabolic dish concentrator uses a parabolic mirror that focuses incoming solar radiation on a receiver mounted above the dish at its focal point. The diameter aimeter of parabolic concentrator made of steel is 2.60 m and the height of disc at centre is 28 cm. The inner surface of the dish is covered by an aluminum foil to make it work as a reflector. The receiver is fixed in an advanced place to the focal point to confirm receiving all dish reflected rays. The receiver is fabricated from steel of 25 cm diameter and 20 cm depth. The receiver shadow on the collector's face can decrease the amount of solar radiation reflected, so the receiver's insulation thickness is limited. The container has two openings, one in the bottom of water interring the container from the brackish water container, and the other from the top for hot water exit to the distiller. The parabolic dish tilt angle was chosen as 30° from the horizontal facing the south, depending on conclusions of reference. However, the focusing system works effectively on direct solar irradiation, which required taking into consideration another loss. The main part of diffused radiation that is about 20% of the solar beam cannot be focused. For this reason, flat collectors are used for low-temperature applications (diffuse radiation is not lost). The setting procedure employed in this study limited the lost diffuse radiation.The focal length of the disc is 72 cm and it is covered with highly reflective silver colored foil of high surface quality and good spectral reflectance and projected area of disc is 1.50 m (Fig. 7). A silver colored foil of high reflectivity is used because of light weight, ease of covering the dish and low cost compared to aluminium foil or glass. The absorber, mounted at the focal point, was made of steel alloy which has a receiving surface of 1.50 m and a geometric concentration of 100. The concentration ratio of this parabolic concentrator is calculated as 38. This pot is completely insulated except the part lit by the solar rays reflected by the parabolic surface. The saline water is kept inside the pot. Glass tube condenser fixed in a wooden box was used in this work. The brackish water is supplied to the glass tube condenser from the concentrating unit where it is condensed. Distilled water was gathered in a jar and measured every operating hour.

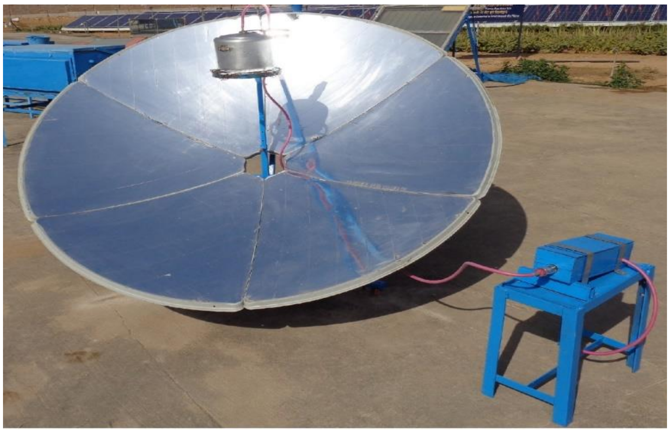

Figure 7: Parabolic concentrating solar thermal desalination device

Fig.8 and Fig. 9 shows the instantaneous distillate yield of the parabolic solar concentrator-based distillation unit in the summer (May 2019) and winter (December 2019) month. The distillate yield was measured with a measuring jar at sixty-minute intervals from 9:00 AM to 17:00 PM. It was observed that steam generation was started after half an hour in each experiment, resulting in production rate of zero at 8:00 am. As the water temperature in the absorber increases, the thermal capacity of the water decreases, causing an increase in the evaporation rate, hence reaching the maximum hourly production rates of at 13.00 hr and decreases thereafter as shown in Fig. 8 and 9. This evolution is closely linked to solar lightening, which is responsible for this production and therefore has a similar rate. This deviation can be explained by the fact that in the morning, only a small part of absorbing surface is covered with water because of the strong tilt in addition to the geometry imperfection and the sun's manual follow-up. In the summer month of May 2019, the total cumulative amount of daily productivity was 6.5 lit.day^{-1},while the productivity in the winter month of December 2019 was 5.50 lit. day^{-1}. The wall temperature of the absorber is increased due to higher values of solar insolation (more than 750 W/m^2) which is the major effective parameter on the productivity. Therefore, steam generation rate and consequently the production rate increase. As the parabolic dish provides concentrated heat flux for the salt water in the absorber, this parameter appears as a driving force for evaporation rate and productivity. In this case, it is expected that the developed point-focus solar still produces acceptable amount of fresh water in high solar intensity weather conditions even in cold and windy hours.

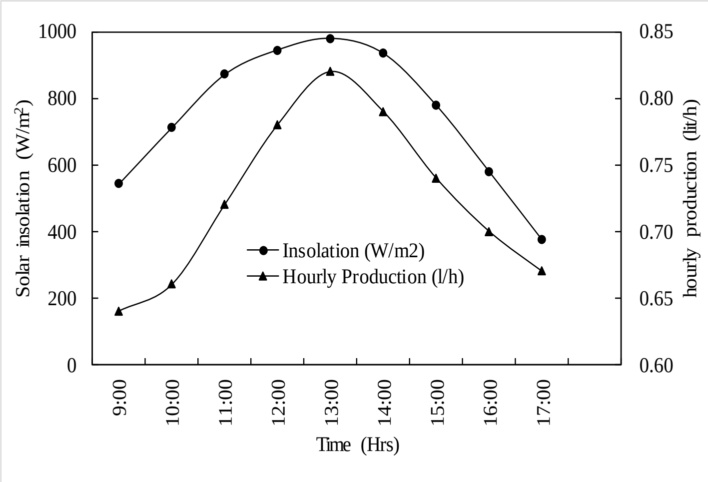

Figure 8: Variation of distillate yield for parabolic concentrating solar thermal desalination device during May 2019

The daily efficiency obtained for all of the five experiments days in summer (May 2019) and winter (December 2019) month is shown in Fig. 10. The maximum average daily efficiency of the parabolic concentrating solar thermal desalination device was 34.2% in month of May and 32.3% in month of December 2019.

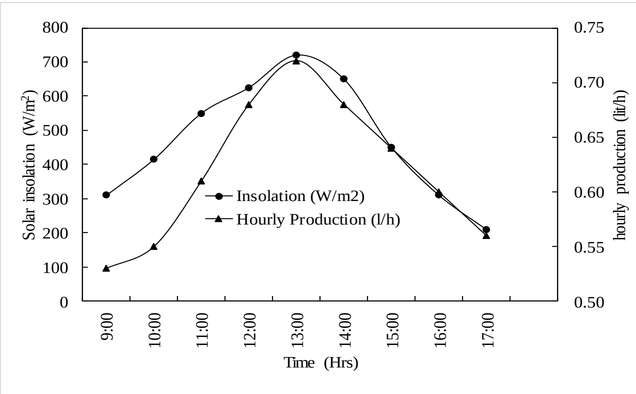

Figure 9: Variation of distillate yield for parabolic concentrating solar thermal desalination device during December 2019

It can be observed that the daily efficiency of the December month is less than that of the May month in all experimental days. The efficiency presents an increase in the beginning; then it has a decrease thereafter. The deviations of efficiency can be explained by the fact that in the beginning, only one part of the absorbing surface is covered with salt water, the manual sun pointing and the existence of imperfections in the concentrator surface. In the other case, the maximum efficiency corresponds to the maximum solar lightning obtained towards 13:00. At this hour, the boiler is nearly in a horizontal position, which maximizes the offered heat transfer surface [37].

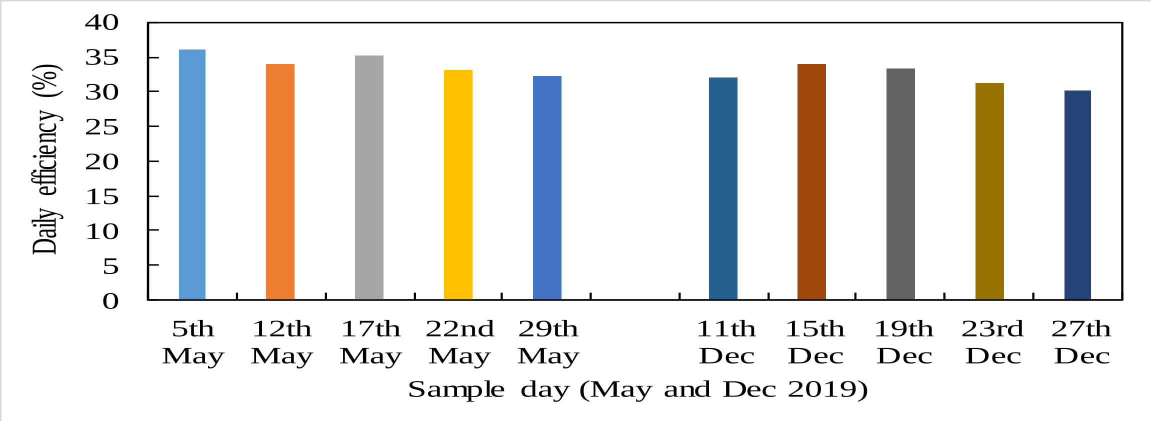

Figure 10: Daily efficiency of the parabolic concentrating solar thermal desalination device obtained for five experiment days in May and Dec 2019.

A comparison between conventional RO plant and parabolic concentrating solar thermal desalination devicewas also done using highly saline and the performance of such units was found to be better than that of conventional RO plant. Electrical concductivity (EC) of raw saline water having salt varying from 4.15 mmhos to 10.50 mmhos that was reduced to 0.94 mmhos to 2.56 mmhos in commercial RO plant while it varied from 0.10mmhos to 0.48mmhos in solar desalination devices respectively.

Conclusion

Solar desalination device is very much useful in rural arid areas which are deprived of potable water and only saline water is available. The device is very cost effective can provide 8 to 10 litres of distilled water per day on clear sunny days. The solar still can be successfully used for desalination of saline water in rural areas for meeting requirement of potable water. The distillate output of solar still can be mixed with the available saline water in appropriate proportion to make it drinkable. In fact as much as 20 litres/day of potable water (150 ppm TDS) can be made available in a day from raw water containing 300 ppm TDS by improved solar still. The use of solar desalination device would help in conservation of conventional fuels, such as firewood, cow dung cake and agricultural waste in rural areas of India. Conservation of firewood helps in preserving the ecosystems and cow dung cake could be used as fertilizer, which could help increase the agricultural production. Moreover, the use of this device would result in the reduction of the release of CO_2 to the environment. The solar desalination unit will overcome the problem of corrosion associated with metallic solar still. In addition, there is a wide scale adoption of distilled water in dispensaries, laboratories, batteries etc.