Efficient desalination by layered heating of saline water

Ronak H Virani¹, B S Patel², H G Katariya³
¹,²,³Mechanical Engineering Department, Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar – 38812, Gujarat, India

e-mail: ¹viranironak1996@gmail.com

Abstract. Thin layer heating technology for desalination is one of the topics that is catching eye of many researchers recently. The sun is a very good renewable energy source that can solve many human being’s problems such as water scarcity. Solar energy can be utilized for water desalination. Nowadays, parabolic trough collector and dish reflector and other optical concentrators are used to concentrate the solar radiation to get more power. They are complex and costly. Efficiency of basin type solar still and other conventional solar still is decreases as we increase water quantity, due to the heat loss to water. Due to this reason need of solar desalination devices that use localized heating of a thin layer of water. In the past few years, significant research is done for the developing thin layer heating desalination. In this paper, basin type solar still is discussed, properties of wood and titanium dioxide materials for substrate and absorber have been discussed and results carried out by experimental performance is discussed. This paper is concerned with effects of change in radiation, effects of change in water depth in basin and effects of change in salinity of water.

Keywords: Desalination, Basin type solar still, Titanium dioxide, Wood.

1. INTRODUCTION

In future, we need to fulfil the increasing demand for fresh water because of the increasing world population [1]. There are many freshwater resources available but these will not be enough. Desalination is considered as very useful to fulfil water demand. There are two methods which are used for desalination of saline water is thermal desalination and reverse osmosis technology. Solar water desalination uses a renewable energy source. It has less impact on the environment. So, this method can be used to reach water demand. Therefore, we need to develop low-cost desalination devices for getting fresh water. In past years it is seen increasing fast advances for the development of layered heating of water type desalination devices.
Bi-layered desalination device is made up of substrate material which is thermal insulator a thin layer of absorber material is deposited onto it as shown in fig. 1. The solar radiation is energy input given to the system. This input is used to evaporation of water. The energy which is absorbed by absorber material is used to heat the thin water layer. The total enthalpy of heat required to change the phase of water from liquid to vapour is reached, the water layer starts to evaporate. Evaporation of water takes place in the absorber layer by water wicked in the micro-pores of substrate material, by the capillary action. If a thin layer of water is heated locally for desalination, water bulk is not heated but the only thin layer is heated. If we heat water bulk there is more heat loss occurs [2].

To get efficient desalination using this device the following features are required:

- The absorber material should have good sunlight absorption to convert sunlight energy into heat.
- Thermal conductivity of substrate material should be very low.
- Whole bi-layered desalination device should float on water.

Conventional solar stills are less efficient and involve more cost. parabolic trough collector and dish reflector and other optical concentrators are used to concentrate the solar radiation to get more power. They are more complex and costly. Efficiency of basin type solar still and other conventional solar still is decreases as we increase water quantity in basin, due to the heat loss to water. To increase efficiency, additional methods required. Due to these reasons we can do more research on methods to increase efficiency of solar stills and we can get low cost and more efficient solar desalination.

Based on above theory, we have made a solar still which is made up of a thin layer acts as an absorber of sunlight, which is deposited layer by layer onto a substrate material acting as thermal insulator between water and the absorbing material. This insulator is floating on the water and the substrate consists of porous structure so water wick up to the absorber surface by using capillary action and absorber absorbs the sunlight. The energy which is absorbed by absorber material is used to heating the thin water layer. Total enthalpy of heat required to change phase of water from liquid to vapour is reached, water layer starts evaporating. Because of layered heating of water, heat loss is reduced and we are getting more efficiency.

Here, we give a brief overview of efficient solar desalination, materials used for substrate and absorbers, new solar desalination device which has titanium dioxide deposited on wood and experimental result and conclusion.

This paper is arranged as follows: Section 2 presents various substrate materials and why wood is used. Section 3 presents experimental setup section 4 presents methodology 5 presents assumptions 6 presents calculations 7 presents result and discussions.

2. SUBSTRATE AND ABSORBER MATERIALS

Absorber which is deposited onto a substrate material acting as a thermal insulator between absorber and water. The substrate should have a low thermal conductivity, it should have good hydrophilicity characteristics for transport water from the water basin to surface. The substrate should consist of porous structure so water wick up to the absorber surface by using capillary action and absorber absorbs the sunlight. The whole structure should have low density and it can float on the water. Various substrate
materials which are easily available are paper, gauze, wool, carbon fabric, cotton fabric, wood, aerogel etc. These materials are porous and possess low density [2].

Paper cannot be used in the real-world application in desalination, because it has very less life in water and its mechanical properties are poor. Carbon fabric and cotton fabric also have less life against water and thermal conductivity of these materials also more [5]. For substrate material, wood and aerogels are more promising materials as they have more life in water, have more strength, good machinability, hydrophilicity, low thermal conductivity [13]. So, these materials can be used as a substrate. Aerogel is more costly than other materials [6]. Wood has the benefit of abundancy and more availability and has low cost [7].

An absorber is deposited onto a substrate. Absorber should good absorber of sunlight to get better conversion of sunlight to heat. Absorber should give chemical stability and non-toxicity. Absorber should have high light to heat conversion capacity. Absorber should be porous material. So, it can easily evaporate water. Various absorber materials which are available are Aluminium, gold, silver, polypyrrole, graphite, graphene oxide, cermet, titanium dioxide, ferroferric oxide etc [2].

Coating of aluminium nanoparticles on the substrate is difficult [8]. Gold and silver have superior optical properties but the cost is high. Materials which are made up of carbon like graphite and graphene oxide are easily available at low cost. High sunlight absorption with the good conversion of light into heat, titanium dioxide and other metal oxides are a good choice. Titanium dioxide has low cost, Non-toxic and good chemical stability. For this reason, titanium dioxide preferred against other absorber materials [9]. Titanium dioxide exists naturally in three crystalline forms anatase, brookite and rutile. Rutile has more light to heat conversion rate [17].

3. EXPERIMENTAL SETUP

A basin type solar still with wood-Titanium dioxide is used for experimental work and other instruments used is shown in figure 2.
3.1. Specifications of setup

- Area of collector – 0.5 m² (8 Wood plate of 0.0625 m²)
- Top cover tilt angle - 23°
- Thickness of wood - 15 mm
- Material of basin - Galvanized iron sheet
4. METHODOLOGY

Titanium dioxide hydro sol is deposited on radial cut pine wood by using paint brush. Wood-Titanium dioxide is placed inside the basin filled with water. Desalination experiment were carried out for 12 days by changing depth of water and salinity of water. 25 February 2020 to 28 February 2020 and 4 March to 7 March, 11 March, 12 March and 14 July, 15 July from 9 A.M. to 5 P.M. at B.V.M. engineering college, Vallabh Vidyanagar, Anand District, Gujarat, India.

For experiment without wood-TiO₂ only basin is used and for experiment with wood-TiO₂ Titanium dioxide deposited wood placed inside the same basin. Titanium dioxide hydro sol has made by using chemical reaction [21].

Different measuring instruments are used for measure temperature, solar radiation and TDS are show in Table No: 1.

| Parameters       | Measuring Instrument | Range       |
|------------------|----------------------|-------------|
| Temperature      | Temperature sensor   | -10 °C – 110 °C |
| TDS              | TDS meter            | 0 – 9990 ppm |
| Solar Radiation  | Pyranometer          | 0 – 1000 W/m² |

Experiments conducted for 12 days.

| Day   | Experiment with/without wood-TiO₂ | TDS of water in basin (ppm) | TDS of output water (ppm) | Water depth in basin (cm) |
|-------|----------------------------------|----------------------------|---------------------------|---------------------------|
| Day 1 | without wood-TiO₂                 | 524                        | 33                        | 10                        |
| Day 2 | with wood-TiO₂                    | 526                        | 35                        | 10                        |
| Day 3 | without wood-TiO₂                 | 542                        | 36                        | 05                        |
| Day 4 | with wood-TiO₂                    | 543                        | 35                        | 05                        |
| Day 5 | without wood-TiO₂                 | 2500                       | 41                        | 10                        |
| Day 6 | with wood-TiO₂                    | 2500                       | 40                        | 10                        |
| Day 7 | without wood-TiO₂                 | 2500                       | 45                        | 05                        |
| Day 8 | with wood-TiO₂                    | 2500                       | 49                        | 05                        |
| Day 9 | without wood-TiO₂                 | 5000                       | 52                        | 10                        |
| Day 10| with wood-TiO₂                    | 5000                       | 54                        | 10                        |
| Day 11| without wood-TiO₂                 | 5000                       | 55                        | 05                        |
| Day 12| with wood-TiO₂                    | 5000                       | 52                        | 05                        |

Water output reading and water temperature was taken at every 30 minutes.

5. ASSUMPTIONS

1. Total volume of water in basin remains same.
2. TDS of basin water remains same.
3. Heat loss from system is negligible.
4. Properties of glass uniform.
5. Heat gain is utilised for evaporation.

6. CALCULATIONS

\[ \eta = \frac{(m \times h \nu) + (M \times C p \times \Delta T)}{I} \]
Where,
- \( \hat{m} \) = Evaporation rate, kg/m\(^2\)s.
- \( h_{lv} \) = Enthalpy requires for change phase of water from liquid to vapour, 2250 kJ/kg.
- \( M \) = Total mass of water, 48 kg.
- \( C_p \) = Specific heat, 4.186 kJ/kg\(\cdot\)K.
- \( \Delta T \) = Change in temperature.
- \( I \) = Incident power density of solar radiation, W/m\(^2\).

7. Results and discussions

Water output and efficiency of experiment is shown in tables. Details of experiments given below.

1. Experiments performed with and without wood-TiO\(_2\).
2. Depth of water – 5 cm and 10 cm.
3. Tds of water - 524 ppm, 2500 ppm, 5000 ppm

Table 3. Experimental data

| Time  | Output without wood-TiO\(_2\) (kg) | Water temperature without wood-TiO\(_2\) | Radiation | Efficiency without wood-TiO\(_2\) | Output with wood-TiO\(_2\)(kg) | Water temperature with wood-TiO\(_2\) | Radiation | Efficiency with wood-TiO\(_2\) |
|-------|---------------------------------|----------------------------------------|-----------|---------------------------------|-------------------------------|--------------------------------------|-----------|------------------------------|
| 10:30 | 0.012                           | 29.2                                   | 511       | 1.87                            | 0.029                         | 29.4                                 | 492       | 1.94                         |
| 11:00 | 0.028                           | 29.3                                   | 540       | 1.17                            | 0.112                         | 30                                   | 532       | 6.52                         |
| 11:30 | 0.049                           | 29.9                                   | 593       | 3.23                            | 0.202                         | 30.8                                 | 591       | 6.95                         |
| 12:00 | 0.078                           | 31.5                                   | 630       | 7.05                            | 0.294                         | 32.6                                 | 666       | 9.73                         |
| 12:30 | 0.108                           | 33.6                                   | 633       | 8.89                            | 0.398                         | 35.1                                 | 657       | 12.80                        |
| 01:00 | 0.142                           | 36.5                                   | 694       | 10.92                           | 0.502                         | 40.1                                 | 637       | 22.33                        |
| 01:30 | 0.174                           | 40.2                                   | 662       | 14.20                           | 0.613                         | 44.9                                 | 614       | 22.69                        |
| 02:00 | 0.221                           | 43.2                                   | 635       | 12.83                           | 0.739                         | 50.6                                 | 603       | 27.20                        |
| 02:30 | 0.258                           | 45.4                                   | 584       | 10.34                           | 0.838                         | 54.8                                 | 568       | 21.55                        |
| 03:00 | 0.285                           | 46.8                                   | 560       | 7.01                            | 0.932                         | 57.8                                 | 508       | 18.35                        |
| 03:30 | 0.315                           | 47                                     | 461       | 2.63                            | 1.023                         | 58.6                                 | 369       | 11.20                        |
| 04:00 | 0.338                           | 47.1                                   | 379       | 2.13                            | 1.128                         | 58.7                                 | 357       | 8.00                         |
| 04:30 | 0.363                           | 47.2                                   | 320       | 2.67                            | 1.2                            | 58.7                                 | 239       | 7.53                         |
| 05:00 | 0.391                           | 47.1                                   | 245       | 1.90                            | 1.268                         | 58.5                                 | 152       | 8.12                         |
| 05:30 | 0.412                           | 46.9                                   | 45        | 1.33                            | 1.326                         | 58                                   | 91        | 3.15                         |

Figure 6. Efficiency comparison for with and without wood-TiO\(_2\)

Table III shows result of experiments at 10 cm water depth and TDS of water is 524 ppm which is normal tank water. Experiments conducted on 25 February, 2020 without wood-TiO\(_2\) and on 26 February, 2020 with wood-TiO\(_2\). Cumulative water output with wood-TiO\(_2\) is more compared to without
In morning time radiation of sun is low, so we get less water output in morning. As radiation increases water output also increases. After 2:00 pm radiation starts decreasing, but decline in water temperature is less because of latent heat of water. Cumulative water output with and without wood-TiO$_2$ is 1.326 kg and 0.412 kg respectively. Maximum temperature with wood-TiO$_2$ is 58.7°C compared to 47.2°C without wood-TiO$_2$.

Maximum efficiency difference with and without wood-TiO$_2$ is 13% between 1:30 pm to 2:00 pm.

Table 4. Experimental data

| Time  | Output without wood-TiO$_2$ (kg) | Water temperature without wood-TiO$_2$ | Radiation | Efficiency without wood-TiO$_2$ | Output with wood-TiO$_2$ (kg) | Water temperature with wood-TiO$_2$ | Radiation | Efficiency with wood-TiO$_2$ |
|-------|---------------------------------|---------------------------------------|-----------|---------------------------------|-----------------------------|-----------------------------------|-----------|-----------------------------|
| 10:30 | 0.018                           | 30.9                                  | 568       | 1.61                            | 0.022                       | 30.9                              | 514       | 1.97                        |
| 11:00 | 0.042                           | 31.2                                  | 582       | 1.63                            | 0.112                       | 31.8                              | 577       | 5.71                        |
| 11:30 | 0.071                           | 32.5                                  | 652       | 3.43                            | 0.205                       | 33.2                              | 563       | 7.02                        |
| 12:00 | 0.101                           | 36.1                                  | 678       | 7.28                            | 0.298                       | 36.8                              | 663       | 9.82                        |
| 12:30 | 0.138                           | 39.9                                  | 702       | 7.61                            | 0.401                       | 41.9                              | 667       | 12.75                       |
| 01:00 | 0.168                           | 46.5                                  | 755       | 11.15                           | 0.529                       | 47                                | 710       | 12.85                       |
| 01:30 | 0.223                           | 54.2                                  | 723       | 14.28                           | 0.658                       | 56.4                              | 686       | 20.63                       |
| 02:00 | 0.292                           | 59.5                                  | 707       | 11.15                           | 0.782                       | 62.9                              | 656       | 16.24                       |
| 02:30 | 0.346                           | 63.9                                  | 624       | 10.36                           | 0.909                       | 67.4                              | 622       | 13.51                       |
| 03:00 | 0.401                           | 65.9                                  | 604       | 6.12                            | 1.033                       | 70.5                              | 555       | 12.08                       |
| 03:30 | 0.451                           | 66.5                                  | 502       | 2.72                            | 1.159                       | 70.7                              | 511       | 6.61                        |
| 04:00 | 0.495                           | 66.7                                  | 431       | 2.55                            | 1.268                       | 70.7                              | 416       | 6.55                        |
| 04:30 | 0.535                           | 65.8                                  | 338       | 2.27                            | 1.373                       | 70.2                              | 326       | 6.26                        |
| 05:00 | 0.566                           | 65.6                                  | 258       | 2.10                            | 1.462                       | 69.5                              | 228       | 6.18                        |
| 05:30 | 0.594                           | 65.1                                  | 102       | 1.16                            | 1.531                       | 68.2                              | 111       | 1.92                        |

Figure 7. Efficiency comparison for with and without wood-TiO$_2$

Table IV shows result of experiments at 5 cm water depth and TDS of water is 542 ppm, which is normal tank water. Experiments conducted on 27 February, 2020 without wood-TiO$_2$ and on 28 February, 2020 with wood-TiO$_2$. Cumulative water output with wood-TiO$_2$ is more compared to without wood-TiO$_2$. In morning time radiation of sun is low, so we get less water output in morning. As radiation increases water output also increases. After 2:00 pm radiation starts decreasing, but decline in water temperature is less because of latent heat of water. Cumulative water output with and without wood-TiO$_2$ is 1.531 kg and 0.594 kg respectively.
Maximum temperature with wood-TiO$_2$ is $70.7^\circ C$ compared to $66^\circ C$ without wood-TiO$_2$.

Maximum efficiency difference with and without wood-TiO$_2$ is 6.35% between 1:30 pm to 2:00 pm.

**Table 5.** Experimental data

| Time  | Output without wood-TiO$_2$ (kg) | Water temperature without wood-TiO$_2$ | Radiation Efficiency without wood-TiO$_2$ | Output with wood-TiO$_2$ (kg) | Water temperature with wood-TiO$_2$ | Radiation Efficiency with wood-TiO$_2$ |
|-------|---------------------------------|--------------------------------------|------------------------------------------|-------------------------------|-----------------------------------|--------------------------------------|
| 10:30 | 0.017                           | 30                                   | 626                                      | 1.05                          | 0.02                              | 29.4                                 |
| 11:00 | 0.038                           | 30.1                                 | 654                                      | 1.15                          | 0.114                             | 29.9                                 |
| 11:30 | 0.06                            | 30.5                                 | 430                                      | 3.44                          | 0.211                             | 30.7                                 |
| 12:00 | 0.082                           | 32.2                                 | 689                                      | 6.53                          | 0.32                              | 32.5                                 |
| 12:30 | 0.113                           | 34.1                                 | 710                                      | 7.31                          | 0.418                             | 35.1                                 |
| 01:00 | 0.142                           | 36.8                                 | 737                                      | 9.50                          | 0.522                             | 40.1                                 |
| 01:30 | 0.176                           | 40.5                                 | 685                                      | 13.80                         | 0.633                             | 45.2                                 |
| 02:00 | 0.213                           | 43.8                                 | 723                                      | 11.89                         | 0.759                             | 51.9                                 |
| 02:30 | 0.247                           | 46.7                                 | 641                                      | 11.84                         | 0.868                             | 55.8                                 |
| 03:00 | 0.279                           | 47.4                                 | 593                                      | 4.09                          | 0.971                             | 58.8                                 |
| 03:30 | 0.309                           | 47.8                                 | 552                                      | 3.04                          | 1.083                             | 59.1                                 |
| 04:00 | 0.335                           | 47.7                                 | 202                                      | 2.06                          | 1.188                             | 59.2                                 |
| 04:30 | 0.357                           | 47.7                                 | 356                                      | 1.54                          | 1.289                             | 59                                  |
| 05:00 | 0.374                           | 47.6                                 | 180                                      | 1.06                          | 1.378                             | 58.7                                 |
| 05:30 | 0.388                           | 47.5                                 | 106                                      | 1.10                          | 1.466                             | 58                                  |

**Figure 8.** Efficiency comparison for with and without wood-TiO$_2$
Table V shows result of experiments at 10 cm water depth and TDS of water is 2500 ppm, which is salt water. Experiments conducted on 4 March, 2020 without wood-TiO$_2$ and on 5 March, 2020 with wood-TiO$_2$. Cumulative water output with wood-TiO$_2$ is more compared to without wood-TiO$_2$. In morning time radiation of sun is low, so we get less water output in morning. As radiation increases water output also increases. After 2:00 pm radiation starts decreasing, but decline in water temperature is less because of latent heat of water. Cumulative water output with and without wood-TiO$_2$ is 1.466 kg and 0.388 kg respectively. Maximum temperature with wood-TiO$_2$ is 59.2°C compared to 47.8°C without wood-TiO$_2$.

Maximum efficiency difference with and without wood-TiO$_2$ is 13.15% between 1:30 pm to 2:00 pm.

Table 6. Experimental data

| Time  | Output without wood-TiO$_2$ (kg) | Water temperature without wood-TiO$_2$ | Radiation | Efficiency without wood-TiO$_2$ | Output with wood-TiO$_2$ (kg) | Water temperature with wood-TiO$_2$ | Radiation | Efficiency with wood-TiO$_2$ |
|-------|---------------------------------|---------------------------------------|-----------|-------------------------------|-------------------------------|-----------------------------------|-----------|---------------------------|
| 10:30 | 0.017                           | 30.9                                  | 626       | 0.9                           | 0.022                         | 30.9                              | 540       | 1.23                      |
| 11:00 | 0.044                           | 31.2                                  | 654       | 1.56                          | 0.112                         | 31.8                              | 568       | 5.8                       |
| 11:30 | 0.071                           | 32.2                                  | 630       | 2.91                          | 0.205                         | 33.2                              | 640       | 6.17                      |
| 12:00 | 0.101                           | 35.8                                  | 689       | 7.16                          | 0.298                         | 36.8                              | 698       | 9.32                      |
| 12:30 | 0.138                           | 39.5                                  | 710       | 7.36                          | 0.401                         | 42                                | 705       | 12.22                     |
| 01:00 | 0.168                           | 45.5                                  | 754       | 10.24                         | 0.507                         | 47.5                              | 712       | 12.70                     |
| 01:30 | 0.217                           | 52.9                                  | 698       | 14.08                         | 0.645                         | 56.4                              | 705       | 19.57                     |
| 02:00 | 0.272                           | 57.9                                  | 693       | 10.3                          | 0.773                         | 62.9                              | 695       | 15.47                     |
| 02:30 | 0.329                           | 60.8                                  | 611       | 7.85                          | 0.901                         | 66.8                              | 646       | 11.97                     |
| 03:00 | 0.386                           | 60.9                                  | 576       | 2.67                          | 1.033                         | 67.8                              | 564       | 7.91                      |
| 03:30 | 0.441                           | 60.8                                  | 552       | 2.28                          | 1.159                         | 67.9                              | 522       | 6.25                      |
| 04:00 | 0.495                           | 60.2                                  | 302       | 2.16                          | 1.268                         | 67.8                              | 448       | 5.82                      |
| 04:30 | 0.535                           | 59.8                                  | 256       | 2.08                          | 1.361                         | 67.2                              | 350       | 4.64                      |
| 05:00 | 0.563                           | 59.6                                  | 180       | 2.59                          | 1.439                         | 66.1                              | 223       | 3.00                      |
| 05:30 | 0.58                            | 59.3                                  | 72        | 1.05                          | 1.498                         | 65                                | 103       | 1.90                      |

Figure 9. Efficiency comparison for with and without wood-TiO$_2$

Table VI shows result of experiments at 5 cm water depth and TDS of water is 2500 ppm, which is salt water. Experiments conducted on 6 March, 2020 without wood-TiO$_2$ and on 7 March, 2020 with wood-TiO$_2$. Cumulative water output with wood-TiO$_2$ is more compared to without wood-TiO$_2$. In
morning time radiation of sun is low, so we get less water output in morning. As radiation increases water output also increases. After 2:00 pm radiation starts decreasing, but decline in water temperature is less because of latent heat of water. Cumulative water output with and without wood-TiO$_2$ is 1.498 kg and 0.580 kg respectively. Maximum temperature with wood-TiO$_2$ is 67.9°C compared to 60.9°C without wood-TiO$_2$.

Maximum efficiency difference with and without wood-TiO$_2$ is 5.49% between 1:30 pm to 2:00 pm.

**Table 7.** Experimental data

| Time | Output without wood-TiO$_2$ (kg) | Water temperature without wood-TiO$_2$ | Radiation | Efficiency without wood-TiO$_2$ | Output with wood-TiO$_2$ (kg) | Water temperature with wood-TiO$_2$ | Radiation | Efficiency with wood-TiO$_2$ |
|------|---------------------------------|--------------------------------------|-----------|-------------------------------|-----------------------------|-----------------------------------|-----------|-----------------------------|
| 10:30| 0.014                           | 28                                   | 635       | 0.98                          | 0.015                       | 29.3                               | 546       | 1.29                         |
| 11:00| 0.026                           | 29.2                                 | 649       | 4.76                          | 0.103                       | 29.8                               | 568       | 5.92                         |
| 11:30| 0.046                           | 30.3                                 | 649       | 4.71                          | 0.194                       | 30.7                               | 656       | 6.65                         |
| 12:00| 0.068                           | 31                                   | 666       | 3.27                          | 0.286                       | 32.2                               | 704       | 8.22                         |
| 12:30| 0.102                           | 32.1                                 | 718       | 4.74                          | 0.381                       | 35.2                               | 736       | 12.70                        |
| 01:00| 0.131                           | 36.4                                 | 737       | 14.55                         | 0.492                       | 39.9                               | 721       | 19.00                        |
| 01:30| 0.158                           | 40.6                                 | 703       | 14.85                         | 0.602                       | 45.2                               | 705       | 21.38                        |
| 02:00| 0.191                           | 44.9                                 | 723       | 14.97                         | 0.722                       | 50.8                               | 684       | 23.42                        |
| 02:30| 0.222                           | 46.7                                 | 641       | 7.73                          | 0.826                       | 55.2                               | 645       | 19.89                        |
| 03:00| 0.256                           | 47.1                                 | 593       | 3.00                          | 0.935                       | 58.8                               | 586       | 18.93                        |
| 03:30| 0.281                           | 47.2                                 | 552       | 1.55                          | 1.042                       | 59                                 | 526       | 5.96                         |
| 04:00| 0.311                           | 47.1                                 | 326       | 1.58                          | 1.112                       | 59.2                               | 458       | 4.83                         |
| 04:30| 0.332                           | 47                                   | 319       | 0.91                          | 1.195                       | 59                                 | 350       | 4.59                         |
| 05:00| 0.352                           | 47                                   | 302       | 1.65                          | 1.268                       | 58.7                               | 292       | 3.86                         |
| 05:30| 0.364                           | 46.9                                 | 91        | 0.74                          | 1.362                       | 57.9                               | 184       | 2.66                         |

![Figure 10. Efficiency comparison for with and without wood-TiO$_2$](image_url)
increases water output also increases. After 2:00 pm radiation starts decreasing, but decline in water temperature is less because of latent heat of water. Cumulative water output with and without wood-TiO$_2$ is 1.362 kg and 0.364 kg respectively. Maximum temperature with wood-TiO$_2$ is 59.2°C compared to 47.2°C without wood-TiO$_2$.

Maximum efficiency difference with and without wood-TiO$_2$ is 9.24% between 1:30 pm to 2:00 pm.

Table 8. Experimental data

| Time  | Output without wood-TiO$_2$ (kg) | Water temperature without wood-TiO$_2$ | Radiation | Efficiency without wood-TiO$_2$ | Output with wood-TiO$_2$ (kg) | Water temperatur with wood-TiO$_2$ | Radiation | Efficiency with wood-TiO$_2$ |
|-------|---------------------------------|---------------------------------------|-----------|-------------------------------|-----------------------------|---------------------------------|-----------|-------------------------------|
| 10:30 | 0.016                           | 30.4                                  | 700       | 0.86                          | 0.02                        | 30.2                            | 700       | 1.19                          |
| 11:00 | 0.048                           | 31                                    | 477       | 3.13                          | 0.112                       | 31.2                            | 636       | 5.44                          |
| 11:30 | 0.069                           | 32.1                                  | 520       | 3.46                          | 0.201                       | 32.8                            | 580       | 7.04                          |
| 12:00 | 0.092                           | 33.2                                  | 916       | 2.02                          | 0.304                       | 36.1                            | 916       | 7.00                          |
| 12:30 | 0.121                           | 39.1                                  | 1012      | 7.49                          | 0.398                       | 41.5                            | 928       | 9.29                          |
| 01:00 | 0.158                           | 45.5                                  | 432       | 19.36                         | 0.504                       | 46.9                            | 432       | 20.66                         |
| 01:30 | 0.192                           | 52.4                                  | 515       | 17.22                         | 0.632                       | 56.6                            | 720       | 20.10                         |
| 02:00 | 0.224                           | 57.4                                  | 897       | 7.37                          | 0.748                       | 62.8                            | 624       | 16.20                         |
| 02:30 | 0.258                           | 59.1                                  | 884       | 3.19                          | 0.852                       | 66.9                            | 884       | 8.33                          |
| 03:00 | 0.286                           | 60.9                                  | 830       | 3.36                          | 0.962                       | 67.7                            | 830       | 4.43                          |
| 03:30 | 0.315                           | 60.7                                  | 735       | 0.66                          | 1.059                       | 67.9                            | 735       | 3.61                          |
| 04:00 | 0.339                           | 60.3                                  | 490       | 0.27                          | 1.145                       | 67.8                            | 586       | 3.47                          |
| 04:30 | 0.368                           | 59.8                                  | 374       | 0.38                          | 1.236                       | 67.1                            | 412       | 3.54                          |
| 05:00 | 0.391                           | 59.4                                  | 207       | 0.53                          | 1.322                       | 66                               | 238       | 3.65                          |
| 05:30 | 0.421                           | 58.9                                  | 172       | 0.98                          | 1.403                       | 64.3                            | 148       | 0.32                          |
Table VIII shows result of experiments at 5 cm water depth and and TDS of water is 5000 ppm, which is salt water. Experiments conducted on 14 July, 2020 without wood-TiO₂ and on 15 July, 2020 with wood-TiO₂. Cumulative water output with wood-TiO₂ is more compared to without wood-TiO₂. In morning time radiation of sun is low, so we get less water output in morning. As radiation increases water output also increases. After 2:00 pm radiation starts decreasing, but decline in water temperature is less because of latent heat of water. Cumulative water output with and without wood-TiO₂ is 1.403 kg and 0.421 kg respectively. Maximum temperature with wood-TiO₂ is 67.9°C compared to 60.9°C without wood-TiO₂.

Maximum efficiency difference with and without wood-TiO₂ is 4.89% between 1:30 pm to 2:00 pm.

7. CONCLUSION
4.
5. From above discussions we can conclude that,
1) From graphs of result and discussion section we can conclude that efficiency with wood-TiO₂ is more compared to without wood-TiO₂.
2) Efficiency difference in both with wood-TiO₂ and without wood-TiO₂ is more for 10 cm water depth compared to 5 cm water depth. Because we got more efficiency as depth of water decreases.
3) As TDS of water increases output is decreases for both with and without wood-TiO₂.
4) Water temperature with wood-TiO₂ is more compared to without wood-TiO₂ for all depth and different TDS of water.

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Nomenclature
TDS - Total dissolved solids
TiO₂ – Titanium dioxide
ppm – Parts per million

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