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# Design, Fabrication and Performance Evaluation of Solar Water Still

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***Abstract*- The paper presents the outcome of a project undertaken to design and fabricate a Solar Water Still, specifically for Jorhat (26.74°N, 94.22°E), Assam considering the quality of water of the region. The turbidity (25 NTU) and the iron content (5.06 mg/lit) are in excess in the water of Jorhat. The Solar Water Still has been designed with suitable insulations and a tilt mechanism. The average intensity of solar radiation in Jorhat is 4.47 kWh/m$^2$/day. The collector used is a black painted Aluminium sheet of 1m$^2$ area. Two glazing surfaces (normal window glass) separated by a distance of 10mm is used. The vessel where the evaporation of the water stored takes place is an angular copper vessel. Copper is used because of its high heat conducting ability. The output obtained is 210 mL on an average on a sunny day. The water was collected for a period of 3 months and physical and chemical tests were conducted in the Public Health Engineering laboratory. The results obtained from the test justified the water output to be of a better quality as it contained low contents of iron (0.55 mg/lit), fluoride (0.160 mg/lit), turbidity (6 NTU) and zero arsenic.**

***Keywords: Solar Water Still, Turbidity, NTU (Nephelometric Turbidity Unit), Glazing, Collector.***

## I. INTRODUCTION

Water is the basic necessity of life on planet Earth. All the living forms are directly or indirectly dependent on water. About 2.5% of the Earth's water is fresh water and 98.8% of that water is in ice and groundwater. India is a country where availability of pure water has always been a problem. In the North-Eastern region, specially in Assam people suffer from various harmful diseases due to this problem. Ability to purify the water is the major concern of the Government at the moment. Doing it with chemical methods and other industrial processes have proved to be more expensive and less efficient. The use of solar energy is the perfect alternative solution to the problem. The advantage of this form of energy is that it is cheap, easily available, non-hazardous and most importantly non-polluting and non-diminishing in nature. Developing a Solar Water Still is a simple way of distilling water, using the heat from the sun to drive evaporation from humid soil and ambient air to cool a condenser film. The current study concentrates on developing a solar water still which can be made locally here in Assam.

## II. LITERATURE REVIEW

In order to find out important factors about solar water still and its parts, a series of studies have been made. Sarma, D. et al. (2014) concluded experimentally that for double glazed flat plate collector the optimum spacing (Air gap) should be 10 mm for minimum heat loss. Lates, R. et al. (2008) experimentally shows that 83.91% efficiency is achievable with 2mm bottom and side insulation width, 0.1 mm absorber plate thickness. Panchal, N. et al. (2011) *proved experimentally that the productivity of a solar water still increases by 35% when coupled with a flat plate collector.* Ali, I. et al. (2012) concluded in his paper that the use of granular activated carbon at the bottom of the solar base increases the evaporation rate. Sethi, A.K. et al. (2013) concluded from his experiments that the distillate output obtained decreases with increase of water depth of the basin. Syed, F. et al. (2013) concluded experimentally that the performance of a solar water still can be increased efficiently by coupling the solar water still with evacuated tubes. In a 3 day experiment the volumetric flow rate of the ordinary still coupled with evacuated tubes increased from 48.7% to 49.5% and finally to 50.2%. Mehta, A. et al. (2011) developed a solar water still that produces 1.5 liters of pure water from 14 liters of dirty water, efficiency of the still being 64.37%. The TDS (total dissolved solids) in the pure water is 81 ppm. Senthilrajan, A. (2012) proved experimentally that by coupling a solar water still with a biomass water heater, its productivity increases during dull sunlight and at night hours by 47.2% compared to day time. Younis, O. et al, (2013) calculated mathematically the performance evaluation of a solar water still of area 0.24 m$^2$ coupled with a Fresnel lens (1.3m$^2$). The overall efficiency of the system was 57%, which is 62% more than the efficiency of simple solar water stills. Singh, P. et al. (2012) concluded that the distillation per unit evaporation area can be increased by decreasing the thermal inertia of the water mass. It was found that the unit produces about 20 liters of distilled water per m$^2$, per standard day, under the same conditions of sunshine that would give a production of 2.5 to 3 liters/m$^2$ day in a conventional, single basin solar still.

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## III. EXPERIMENTAL SETUP

The average intensity of solar radiation over Jorhat region is 4.47 kWh/m$^2$/day [3]; with an average atmospheric temperature around 25º C. The latitude and longitude angle for Jorhat is 26.74°N and 94.22°E respectively. Considering the above data about the location a solar water still has been designed and fabricated to evaluate the viability of the system as replacement of conventional water filtration system. The design is based on “Eliodomestico” solar water still. As stated before, modifications are incorporated to increase the output. Figure-1 shows a schematic diagram of the prototype.

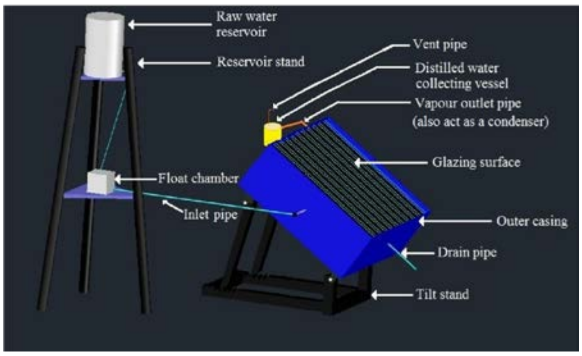


Figure 1: Schematic diagram of the prototype.

The detailed description of the major components of the system is given below:

*The vaporizer:* It is basically an angular copper vessel, which is connected firmly to the collector plate by nuts and bolts. The heat from the collector plate heats up the vessel along with the small amount of water kept inside it. When temperature rises, raw water starts evaporating. The water vapor thus produced get condensed in the condenser and collected. The copper vessel is made of 5mm thick copper plates which are joined by silver brazing. The vessel is then attached with the black coated aluminium collector plate with the help of nut and bolts. There are two pipes at the bottom of the copper vessel, one of which works as inlet while the other is used for flushing purpose (drain pipe). The outlet pipe is at the side of the vessel placed in such way that when the arrangement is inclined, the outlet is at the topmost position. The shape of the vaporizer is so chosen that when the whole system is tilted at 41˚ (41˚ being the optimum tilt angle for Jorhat), the base of the vessel remains parallel to the horizontal surface. This actually gives a better spread of the raw water over the base, increasing the heat transfer.

*Collecting vessel:* The outlet is connected to a collecting vessel. The material of the vessel is chosen as stainless steel, which is safe for drinking water. A small vent pipe with a bent head is attached at the top surface. Steam from the vaporizer, while coming through the copper outlet pipe of 12.7 mm (0.5 inch) diameter, get condensed; and get collected in the collecting vessel. The uncondensed steam and air inside the collecting vessel leaves through the vent pipe. The bent shape of the vent pipe prevents rain water and dust from entering the vessel.

*Collector plate:* A black painted aluminium plate of 2 mm thickness and 1 m$^2$ surface area is used for absorbing the incident solar radiation which acts as the collector plate.

*Glazing surface:* To minimize top heat loss two 5mm thick window glasses separated by a distance of 10mm are used as glazing [15].

*Insulations:* Insulations are provided at the sides and bottom of the vaporizer to prevent heat loss. The walls of the vaporizer are covered using glass wool up to 200mm followed by 200mm of thermocol, to reduce cost and to give better airtight packing. Though thermocol has lower thermal conductivity (0.03 W/m.K) than glass wool (0.04 W/m.K)[17], thermocol cannot be used near the vaporizer, which will, otherwise melt due to the high temperature of the vaporizer walls. Figure-2 shows internal arrangement of the designed solar still.

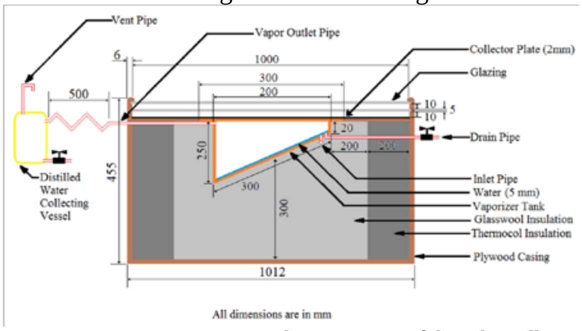


Figure 2: Internal arrangement of the solar still.

*Outer casing:* The vaporizer along with the insulations around it, is kept inside a box made of 6mm thick plywood. The plywood box is further covered with a thin polythene to prevent rain from getting inside the box.

*Float chamber*: A rectangular float chamber is made enclosing a float valve. The function of the float valve is to maintain the level of water inside the vaporizer. It maintains the water level inside the vaporizer tank at 5 mm. Figure-3 shows a pictorial view of the float chamber.

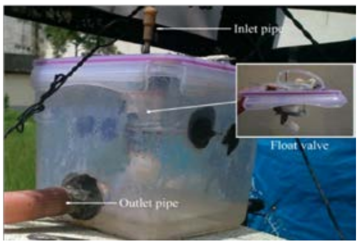


Figure 3: Float Chamber.

*Tilt frame:* A wooden tilt frame is incorporated to the design, so that the solar still can be kept at a desired angle.

As Jorhat is in northern hemisphere, the prototype is placed facing south. As optimum tilt angle for Jorhat is 41˚(refer to design analysis), the arrangement is tilted to 49˚ to the horizontal earth surface to ensure a tilt angle of 41º. Figure-4 shows a pictorial view of the field setup of the prototype.

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Figure 4: Pictorial view of the field setup of the prototype.

## IV. DESIGN CALCULATIONS

Here the optimum tilt angle is calculated along with the thickness of insulation.

The optimum tilt angle (δ) for a place is given by,

δ= latitude ± 15° [18],

Where, 15° is added to the latitude of the place if the design is intended for winter months and subtracted from the latitude if it will be primarily used during summer months.

For Jorhat latitude = 26°75´

Therefore, optimum tilt angle for Jorhat

$\delta_{jorhat}$=26°75´+15°=41°75´≈41° (considering winter months).

*Heat Losses and Insulation Required*

Heat loss from the system occurs from the bottom, side and through top of the vessel. To keep the heat loss through the bottom to 10 W/m$^2$, if „t" be the thickness of glass wool (thermal conductivity= 0.04 W/m.K) insulation required combining with 6 mm(0.006 m) of plywood (thermal conductivity= 0.13 W/m.K) when collector temperature ($T_c$) is assumed as 100°C and atmospheric temperature ($T_a$) is 25°C,then according to the following equation we get

$$\text{Rate of heat loss} = \frac{Temperature\ difference}{Total\ resistance}$$

$$\Rightarrow \quad 10 = \frac{100-25}{\frac{t}{0.04}+\frac{0.006}{0.13}}$$

$$\Rightarrow \quad t = 298 \text{ mm}$$

300 mm of glass wool as shown in Fig. 2 is used as bottom insulation when measured from the middle point of the base. With respect to (1mx1m) collector the sides insulations required are also shown in Figure-2.

The following assumptions are made while calculating the heat losses:

1. Steady state conditions.
2. No heat transfer from edges and corners of the vaporizer tank.
3. Heat transfer area corresponds to the dimensions of the vaporizer tank.
4. Thermal heat loss from the collector plate through insulation depth is neglected.
5. Resistance offered by 6mm plywood is neglected.

A detailed dimensional view and an isometric view of the vaporizer tank is shown in Figure-5 and Figure-6 respectively.

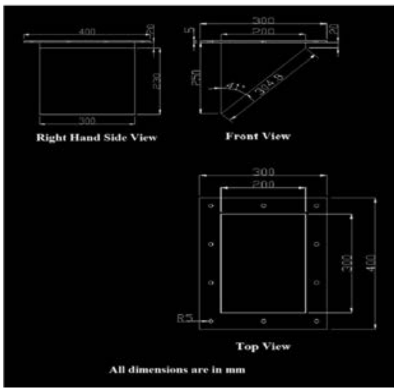


Figure 5: Detailed dimensional view of the vaporizer tank.

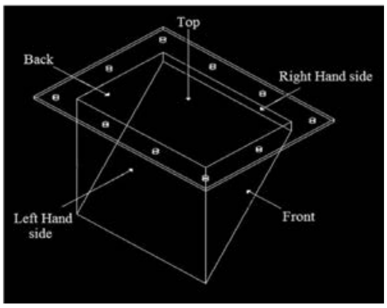


Figure 6: Isometric wireframe view of the vaporizer tank.

The network diagram for the calculations of heat loss from the vaporizer tank to the surroundings is shown in Figure-7.

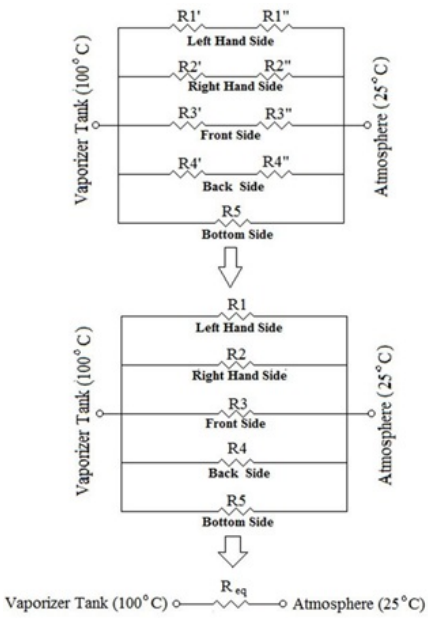


Figure 7: Resistance network diagram.

The area of the surfaces are-

Top surface (300 mm ×200 mm) =0.06 m$^2$ Bottom surface (300 mm ×305 mm) = 0.0915 m$^2$

Left hand side surface (300 mm ×250 mm) = 0.075 m$^2$

Right hand side surface (20 mm ×300 mm) = 0.006 m$^2$

Front and back surface (20x$\frac{250x20}{2}$) = 0.027 m$^2$ each

As the bottom insulation is 300 mm of glass wool the corresponding insulations used are-

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For right hand and left hand side surfaces 200 mm of glass wool (thermal conductivity= 0.04 W/m. K) and 200 mm of thermocol (thermal conductivity= 0.03 W/m. K) on each side. For the front and back surfaces 175 mm of glass wool and 175 mm of thermocol on each side.
The individual resistance of the network are-

For the left hand side surface $R_1 = R_1' + R_1''$

$$= \frac{0.20}{0.03 \times 0.075} + \frac{0.20}{0.04 \times 0.075}$$

= 155.55 K/W

For the right hand side surface $R_2 = R_2' + R_2''$

$$= \frac{0.20}{0.03 \times 0.006} + \frac{0.20}{0.04 \times 0.006}$$

=1944.44 K/W

For the front and back surfaces

$R_3 = R_4 = (R_3' + R_3'')$ or $(R_4' + R_4'')$

$$= \frac{0.175}{0.03 \times 0.027} + \frac{0.175}{0.04 \times 0.027}$$

= 378.08 K/W

For bottom surface $R_5 = \frac{0.30}{0.04 \times 0.0915}$

= 81.97 K/W

Where $R_i'$ is resistance due to thermocol insulations and $R_i''$ is the resistance due to glass wool insulation. The resistance $R_5$ is completely due to glass wool insulation.

The resistances are in parallel. If $R_{eq}$ be the equivalent resistance then

$$\frac{1}{Req} = \frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} + \frac{1}{R4} + \frac{1}{R5}$$

$$= \frac{1}{155.55} + \frac{1}{1944.44} + \frac{1}{378.08} + \frac{1}{378.08} + \frac{1}{81.97}$$

=0.0244 W/K

Therefore $R_{eq}$ = 40.98 K/W or 40.98 °C/W

The heat loss through the bottom and the sides

$$Q = \frac{100-25}{Req} = \frac{100-25}{40.98} = 1.83 \text{ W}$$

The dimensions of the designed parts are shown in Table 1.

| **Parts** | **Materials** | **Dimensions** |
|---|---|---|
| Glazing surface | Glass(2 pieces) | 1m x 1m |
| Collector plate | Aluminium | 1m x 1m |
| Copper vessel | copper | 1 ft. x 1 ft. (4 Pieces) |
| Bottom insulations | Glass wool | Thickness-30 cm |
| Side Insulation | (a) Thermocol | Thickness- 20 cm |
| | (b) Glass wool | Thickness- 20 cm |
| Plywood Box | Plywood (6mm) | L- 106cm, B-106cm, H- 42 cm |
| Tilt stand | wood | --------- |
| Water reservoir stand | Bamboo | Height- 170cm |
| Float valve arrangement | Plastic | --------- |
| Pipes | G.I | ½ inch diameter |
| Ball Valve | Brass | ½ inch diameter |
| Collecting Vessel | Stainless steel | ---------- |

## V. RESULTS AND DISCUSSION

After installation of the prototype, data collection is done for the months of February, March and April of the year 2015. Every day at around 1 PM the weather temperature is noted and collected distillated water is measured at 7 PM. At the same time the raw water is replenished in the raw water reservoir and remaining water in the vaporizer tank is drained out.
Figure-8 shows an overall graphical representation of the temperature and collected water output. The actual experimental data collected during months February, March and April are shown in Annexure (Table 1, Table 2 and Table 3).

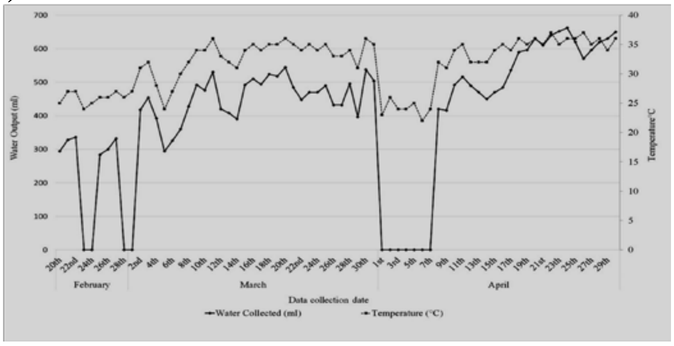


Figure 8:An overall representation of water output during February, March and April with temperature.

The maximum output obtained was 662 ml on 24th of April, temperature being 36° C. On rainy days no distillate was obtained. From the graph (Figure-8) it can be seen that distill water output from the still depends on the weather temperature of the day. High weather temperature leads to low heat loss and less amount of heat is required to evaporate the water.
Table 2 shows a tally of the three water samples, raw water (deep tube well water), tap water (chemically treated water) and project output, tested at Public Health Engineering Laboratory, Jorhat (Assam).

Table 2: Tally of the tests conducted

| Parameter Name | Desirable Limit | Results | | | | |
|---|---|---|---|---|---|---|
| | | Raw Water | J.E.C Tap Water | Project Output | | |
| TDS | **5.0 – 10** | **25** | **17** | **06** | **NIL** | **NTU** |
| Conductivity | 500 – 2000 | 146 | 129 | 60 | 68 | mg/lit |
| pH value | 500 – 2000 | 298 | 263.4 | 123.4 | --- | µS/cm |
| Iron as Fe | 6.5 – 8.5 | 7.14 | 7.36 | 7.14 | 6.92 | mg/lit |
| Total Alkalinity as CaCo3 | **0.2 – 1.0** | **5.06** | **3.34** | **0.55** | **0.22** | **mg/lit** |
| Arsenic | 200 - 600 | 148 | 152 | 42 | --- | mg/lit |
| Fluoride | **0.05** | **0.039** | **0.024** | **0** | **---** | **mg/lit** |
| TDS | 1.0 - 1.5 | 0.70 | 0.45 | 0.160 | NIL | mg/lit |
| Conductivity | **5.0 – 10** | **25** | **17** | **06** | **NIL** | **NTU** |

It is evident from the above table that the turbidity content is found to be nil as compared to the other samples. Also harmful minerals like Arsenic (prolonged exposure can lead to Cancer), and Fluoride (responsible for tooth decay, cavities etc.) are found to be nil whereas Iron (responsible for coloring of water

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and works as a medium for growth of bacteria) is found within the desirable limit.

A bacterial test was done to check bacterial contamination in the output water. The test was done with the help of a Blue Bacta Vial. In the Blue Bacta Vial test, the water does not turn black in colourand hence it can be concluded that the project output is fit for drinking. The video of the Blue Bacta Vial test performed can be found on the following link: https://youtu.be/znYtVU7lVcc.

## VI. CONCLUSION

The Solar Water Still System was installed and output water was collected for the months of February, March and April. The amount of water obtained was at an average of 400-410 ml per day. Maximum output obtained was 662 ml of distilled water on an average sunny day. Tests were conducted on the collected sample and comparisons were made between the raw water supplied for purification in the college campus, the college supply water (chemically treated) and the collected output. The results show, the project output contains low contents of iron (0.22 mg/lit) and zero fluoride, turbidity and arsenic; hence it can be concluded that the project output is safe for drinking. Moreover the model require no maintenance cost and hence makes it economical for use. There is scope of further experimentation to study the system performance incorporating the following attachments:

- Attachment of tracking system
- Use of selective coatings
- Use of a suction pump
- Multistage distillation system

Appendix 1: Record showing water output during February'15

| DATE | QUANTITY COLLECTED | WEATHER TEMPERATURE ( $^0$C) | WEATHER CONDITION |
|---|---|---|---|
| 20.02.15 | 367.5 | 25 | Cloudy |
| 21.02.15 | 328 | 27 | Partly cloudy |
| 22.02.15 | 336 | 27 | Partly cloudy |
| 23.02.15 | 0 | 24 | Rainy |
| 24.02.15 | 0 | 25 | Rainy |
| 25.02.15 | 284 | 26 | Cloudy |
| 26.02.15 | 300 | 26 | Cloudy |
| 27.02.15 | 332 | 27 | Cloudy |
| 28.02.15 | 0 | -- | Rainy |

Appendix 2: Record showing water output during March'15

| DATE | QUANTITY COLLECTED | WEATHER TEMPERATURE ($^0$C) | WEATHER CONDITION |
|---|---|---|---|
| 01.03.15 | 0 | 27 | Rainy |
| 02.03.15 | 418 | 31 | Partly cloudy |
| 03.03.15 | 454 | 32 | Scattered Clouds |
| 04.03.15 | 392 | 28 | Cloudy |
| 05.03.15 | 294 | 24 | Partly Sunny |
| 06.03.15 | 326 | 27 | Partly Sunny |
| 07.03.15 | 360 | 30 | Scattered Clouds |
| 08.03.15 | 428 | 32 | Partly cloudy |
| 09.03.15 | 492 | 34 | Sunny |
| 10.03.15 | 476 | 34 | Sunny |
| 11.03.15 | 530 | 36 | Sunny |
| 12.03.15 | 420 | 33 | Sunny |
| 13.03.15 | 408 | 32 | Scattered Clouds |
| 14.03.15 | 390 | 31 | Partly cloudy |
| 15.03.15 | 492 | 34 | Sunny |
| 16.03.15 | 510 | 35 | Sunny |
| 17.03.15 | 494 | 34 | Sunny |
| 18.03.15 | 524 | 35 | Sunny |
| 19.03.15 | 518 | 35 | Sunny |
| 20.03.15 | 544 | 36 | Sunny |
| 21.03.15 | 484 | 35 | Sunny |
| 22.03.15 | 448 | 34 | Sunny |
| 23.03.15 | 470 | 35 | Sunny |
| 24.03.15 | 470 | 34 | Sunny |
| 25.03.15 | 490 | 35 | Sunny |
| 26.03.15 | 432 | 33 | Sunny |
| 27.03.15 | 432 | 33 | Sunny |
| 28.03.15 | 496 | 34 | Sunny |
| 29.03.15 | 396 | 31 | Partly cloudy |
| 30.03.15 | 538 | 35 | Sunny |
| 31.03.15 | 504 | 35 | Sunny |

Appendix 3: Record showing water output during April 2015

| DATE | QUANTITY COLLECTED | WEATHER TEMPERATURE ($^0$C) | WEATHER CONDITION |
|---|---|---|---|
| 01.04.15 | 0 | 23 | Rainy |
| 02.04.15 | 0 | 26 | Rainy |
| 03.04.15 | 0 | 24 | Rainy |
| 04.04.15 | 0 | 24 | Rainy |
| 05.04.15 | 0 | 25 | Rainy |
| 06.04.15 | 0 | 22 | Rainy |
| 07.04.15 | 0 | 24 | Rainy |
| 08.04.15 | 420 | 32 | Partly cloudy |
| 09.04.15 | 416 | 31 | Scattered Clouds |
| 10.04.15 | 492 | 34 | Sunny |
| 11.04.15 | 516 | 35 | Sunny |
| 12.04.15 | 490 | 32 | Partly cloudy |
| 13.04.15 | 470 | 32 | Sunny |
| 14.04.15 | 450 | 32 | Sunny |
| 15.04.15 | 470 | 34 | Partly cloudy |
| 16.04.15 | 484 | 35 | Scattered Clouds |
| 17.04.15 | 536 | 34 | Sunny |
| 18.04.15 | 590 | 36 | Sunny |
| 19.04.15 | 596 | 35 | Partly cloudy |
| 20.04.15 | 630 | 36 | Sunny |
| 21.04.15 | 610 | 35 | Sunny |
| 22.04.15 | 640 | 37 | Sunny |
| 23.04.15 | 652 | 35 | Sunny |
| 24.04.15 | 662 | 36 | Sunny |
| 25.04.15 | 620 | 36 | Sunny |
| 26.04.15 | 570 | 37 | Sunny |
| 27.04.15 | 596 | 35 | Sunny |
| 28.04.15 | 620 | 36 | Sunny |
| 29.04.15 | 630 | 34 | Sunny |
| 30.04.15 | 650 | 36 | Sunny |

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