PROJECT SEMINAR

Desalination of sea water by Solar Energy

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INTRODUCTION:

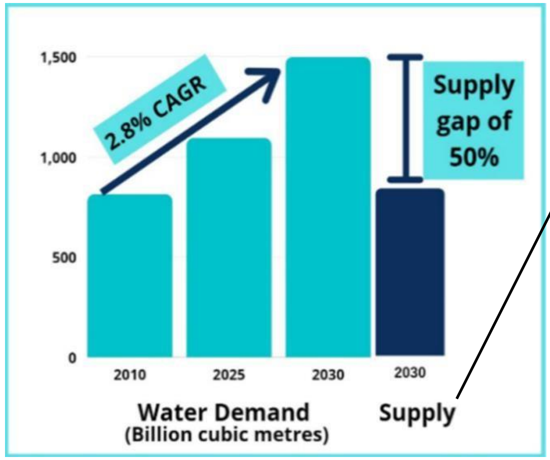
- India is one of the most populous countries in the world, which supports about 17.1% (> 1.3 billion) of world's population and about 500 millions livestock that accounts for 20% of world's livestock population.
- On account of rapid economic and demographic change, the water demands in all the sectors are increasing. According to the projections by National Commission on Integrated Water Resources Development (NCIWRD) the irrigation sector alone is going to need an additional 71 bcm by 2025 and 250 bcm (billion cubic meters) of water by 2050 compared to the demands of 2010 (Press Information Bureau 2013).
- A NITI Aayog report in 2018 stated bluntly that 600 million people, or nearly half of India's population, face extreme water stress.

Table 6.1.1 Projected Water Demand in India
(By Different Use)

Sector	Water Demand in BCM (Billion Cubic Meter)								
	Standing Sub-Committee of MOWR			NCIWRD					
	2010	2025	2050	2010		2025		2050	
				Low	High	Low	High	Low	High
Irrigation	688	910	1072	543	557	561	611	628	807
Drinking Water	56	73	102	42	43	55	62	90	111
Industry	12	23	63	37	37	67	67	81	81
Energy	5	15	130	18	19	31	33	63	70
Other	52	72	80	54	54	70	70	111	111
Total	**813**	**1093**	**1447**	**694**	**710**	**784**	**843**	**973**	**1180**

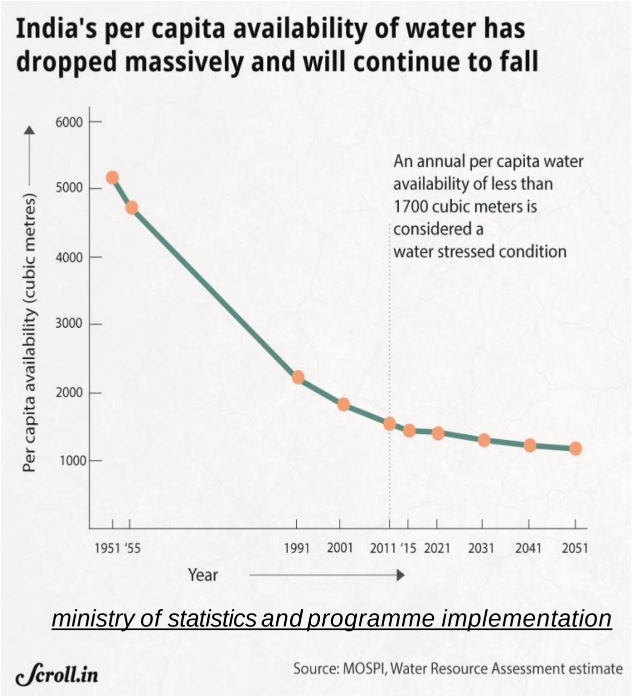
Table: **Information about the section wise water demand is given by the Press Information bureau of India in 2013.**

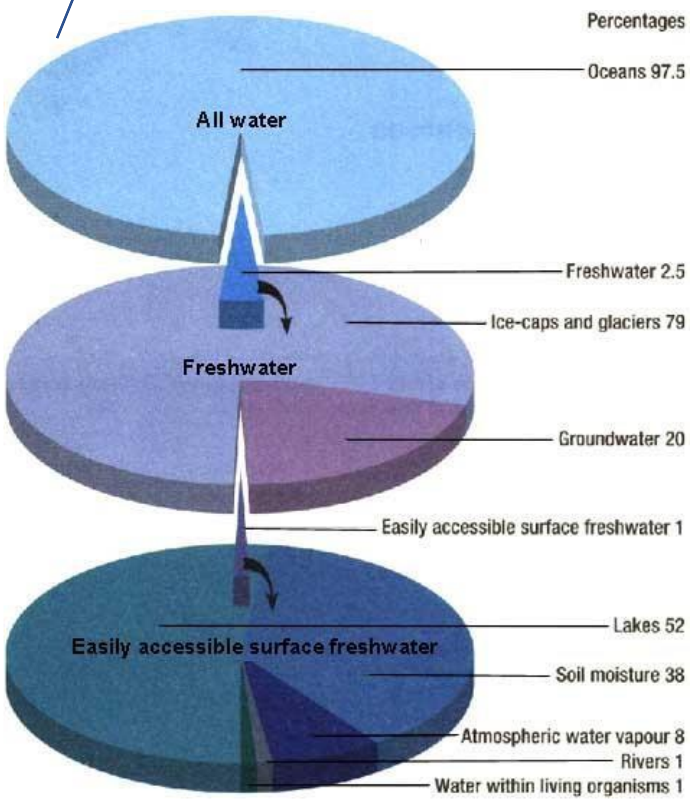
Water Availability



Source: *The 2030 Water Resources Group Data.*

The demand for water in India is expected to grow at a 2.8% Compounded Annual Growth Rate (CAGR) from 2010 to 2030, facing a supply gap of 50% by 2030.





DESALINATION PLANTS BOTH IN INDIA AND ACROSS THE WORLD :

INDIA DESALINATION PLANTS:

- Minjur Seawater Desalination Plant

The **Minjur Desalination Plant** is a ***reverse osmosis***, water desalination plant at Kattupalli village, a northern suburb of Chennai, India, on the coast of the Bay of Bengal that supplies water to the city of Chennai. During droughts, water from the plant will be supplied to the public, serving an estimated population of 1,000,000.

CAPACITY : It produces a 100 million liters per day

- Nemmeli Seawater Desalination Plant

The **Nemmeli Desalination Plant** is a water desalination plant at Nemmeli, Chennai, on the coast of the Bay of Bengal that supplies water to the city of Chennai. The plant treats the seawater by means of several units, including those containing *disc filters and ultra filtration membranes*, to remove the suspended solids in the seawater. Then the water is sent to the final stage of the treatment process through *reverse osmosis membranes* before distribution, which reduces the total dissolved solids in seawater from about ***40,000 parts per million (ppm) to 300 ppm***, thus making it potable.

CAPACITY : Initially started with 50 MLD and expanded up to 100 MLD.

- *UPCOMING DESALINATION PLATS ARE DAHEJ(100 MLD), DWARAKA(70 MLD), GHOGHA BHAVNAGAR(70 MLD), GIR SOMNATH(30 MLD)*

Minjur Desalination plant

Nemmeli Desalination plant

100 MLD Nemmeli Desalination Plant.

GLOBAL DESALINATION PLANTS

COUNTRY	PLANT NAME	CAPACITY
Saudi Arabia	Ras Al Khair	1,036,000 m3/day
UAE	Taweelah	909,200 m3/day
Saudi Arabia	Shuaiba	880,000 m3/day
Saudi Arabia	Jubail Water and power Company(JWAP)	800,000 m3/day
UAE	Umm Al Quwain(UAQ)	682,900 m3/day
Dubai	DEWA StationM	636,000 m3/day
Israel	Sorek	624,000 m3/day
Saudi Arabia	Jubail 3AIWP	600,000 m3/day
Israel	Sorek 2	570,000 m3/day

DESALINATION TECHNIQUES :

Two distillation technologies are used primarily around the world for desalination: thermal distillation and membrane distillation.

THERMAL TECHNOLOGIES:

- Multi-stage flash distillation

Multi-stage flash distillation is a process that sends the saline feed water through multiple chambers. In these chambers, the water is heated and compressed to a high temperature and high pressure.

- Multi-effect distillation

Multi-effect distillation employs the same principals as the multi-stage flash distillation process except that instead of using multiple chambers of a single vessel, MED uses successive vessels

- Vapor compression distillation

VCD uses heat from the compression of vapor to evaporate the feed water

- Solar distillation

The sun provides the energy to evaporate the saline water. The water vapor formed from the evaporation process then condenses on the clear glass or plastic covering and is collected as fresh water in the condensate trough.

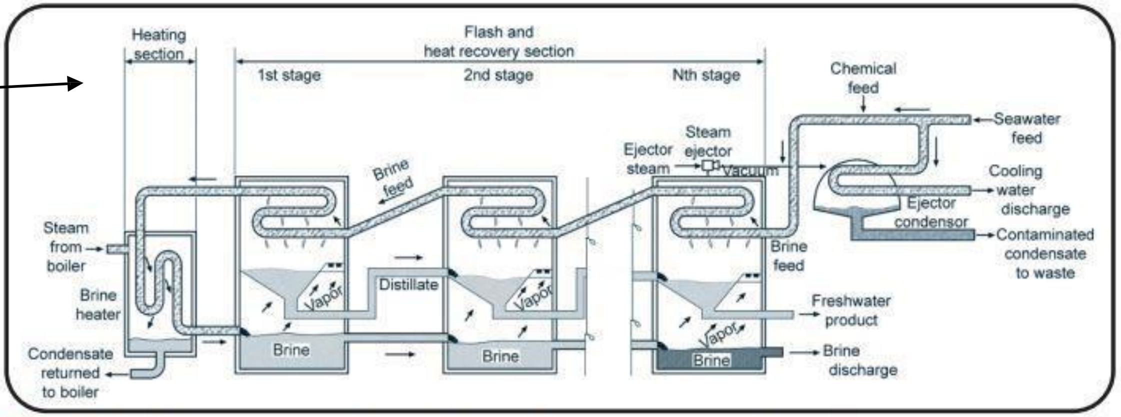


Figure 1. Example of a multi-stage flash distillation (MSF) process (Source: Buros, 1990).

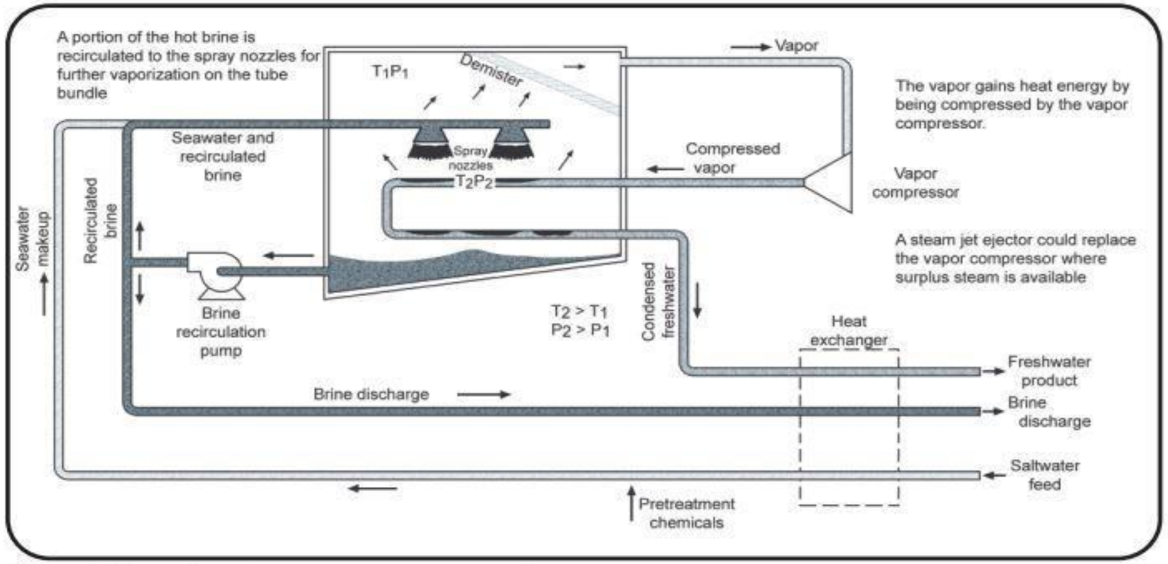


Figure 3. Example of a vapor compression distillation (VCD) process (Source: Buros, 1990).

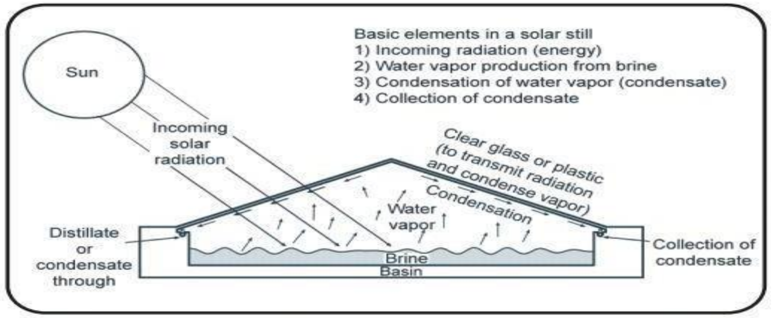


Figure 4. Example of a solar still desalination process (Source: Buros, 1990).

MEMBRANE TECHNOLOGIES

Table 1. General characteristics of membrane processes (Source: Metcalf and Eddy, 2003).

Membrane process	Membrane driving force	Typical separation mechanism	Operating structure (pore size)	Typical operating range, (μm)	Permeate description	Typical constituents removed
Microfiltration	Hydrostatic pressure difference or vacuum in open vessels	Sieve	Macropores (> 50 nm)	0.08–2.0	Water + dissolved solutes	TSS, turbidity, protozoan oocysts and cysts, some bacteria and viruses
Ultrafiltration	Hydrostatic pressure difference	Sieve	Mesopores (2–50 nm)	0.005–0.2	Water + small molecules	Macromolecules, colloids, most bacteria, some viruses, proteins
Nanofiltration	Hydrostatic pressure difference	Sieve + solution/ diffusion + exclusion	Micropores (< 2 nm)	0.001–0.01	Water + very small molecules, ionic solutes	Small molecules, some hardness, viruses
Reverse osmosis	Hydrostatic pressure difference	Solution/ diffusion + exclusion	Dense (< 2 nm)	0.0001–0.001	Water + very small molecules, ionic solutes	Very small molecules, color, hardness, sulfates, nitrate, sodium, other ions
Dialysis	Concentration difference	Diffusion	Mesopores (2–50 nm)	--	Water + small molecules	Macromolecules, colloids, most bacteria, some viruses, proteins
Electrodialysis	Electromotive force	Ion exchange with selective membranes	Micropores (< 2 nm)	--	Water + ionic solutes	Ionized salt ions

ELECTRODIALYSIS & ELECTRODIALYSIS REVERSAL

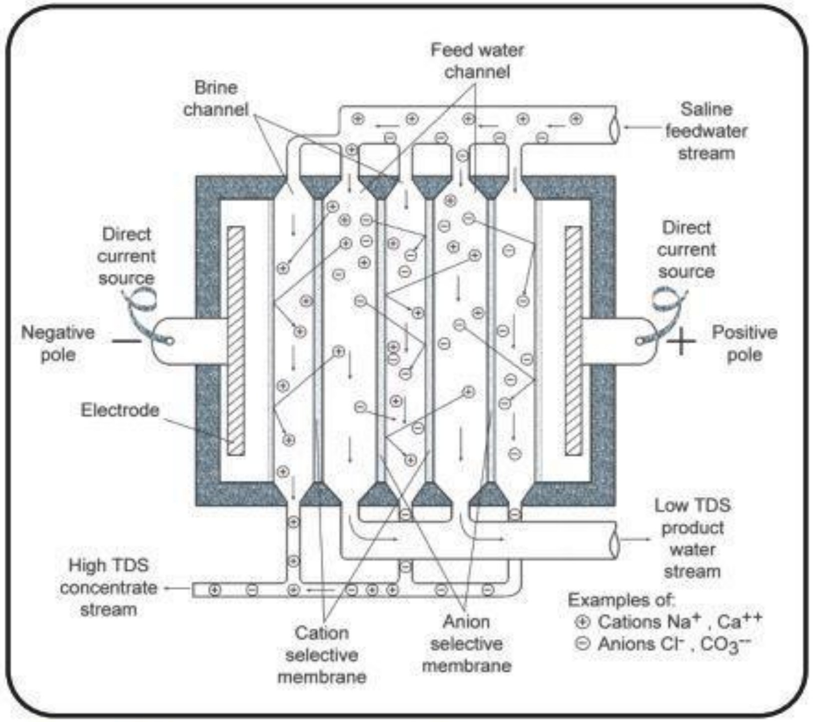


Figure 5. Example of an electrodialysis process showing the basic movements of ions in the treatment process (Source: Buros, 1990).

REVERSE OSMOSIS

Reverse osmosis uses a pressure gradient as the driving force to move high-pressure saline feed water through a membrane that prevents the salt ions from passing. The RO membrane has small pores, the feed water must be pretreated adequately before being passed through it. The water can be pretreated chemically, to prevent biological growth and scaling, and physically, to remove any suspended solids.

ADVANTAGES of Desalination	DISADVANTAGES of Desalination
• Sea water is an "Unlimited Source"	• Desalination is an energy intensive process
• Many large cities are located next to the sea	• Investment and operation costs are very high
• For some countries it is the only access to fresh water	• Brine discharge can effect the environment
• Migration from country site due to fresh water scarcity can be reduced	• Brine discharge of brackish water desalination inside the country is difficult
• Available in areas of drought	• Green house gas emissions
• Production of a high yield of water	• High price
• Water scarcity can be easily handled	• Water quality problem
• Multiple industries benefit from the presence of desalination facilities.	• Some desalination efforts remove the electrolytes from the water supply.
• We could use the water movement from desalination to create more energy.	• Desalination does not create a helpful water ratio.

DESALINATION BY SOLAR ENERGY:

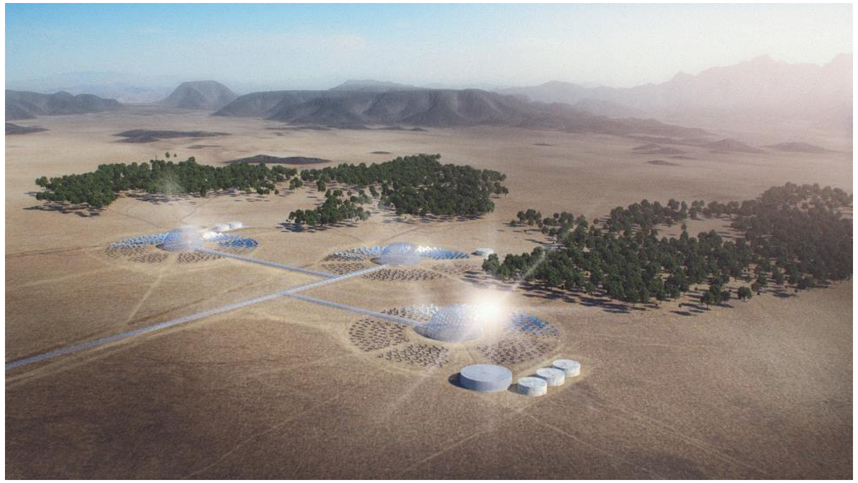
Solar Water Desalination plant is helping solve the planet's water crisis, with a zero-environmental impact and affordable system

HOW IT WORKS:

Concentrated Solar Power Desalination plants combine technologies that provide a sustainable approach to seawater desalination using only the sun as the energy source.

THE PROCESS :

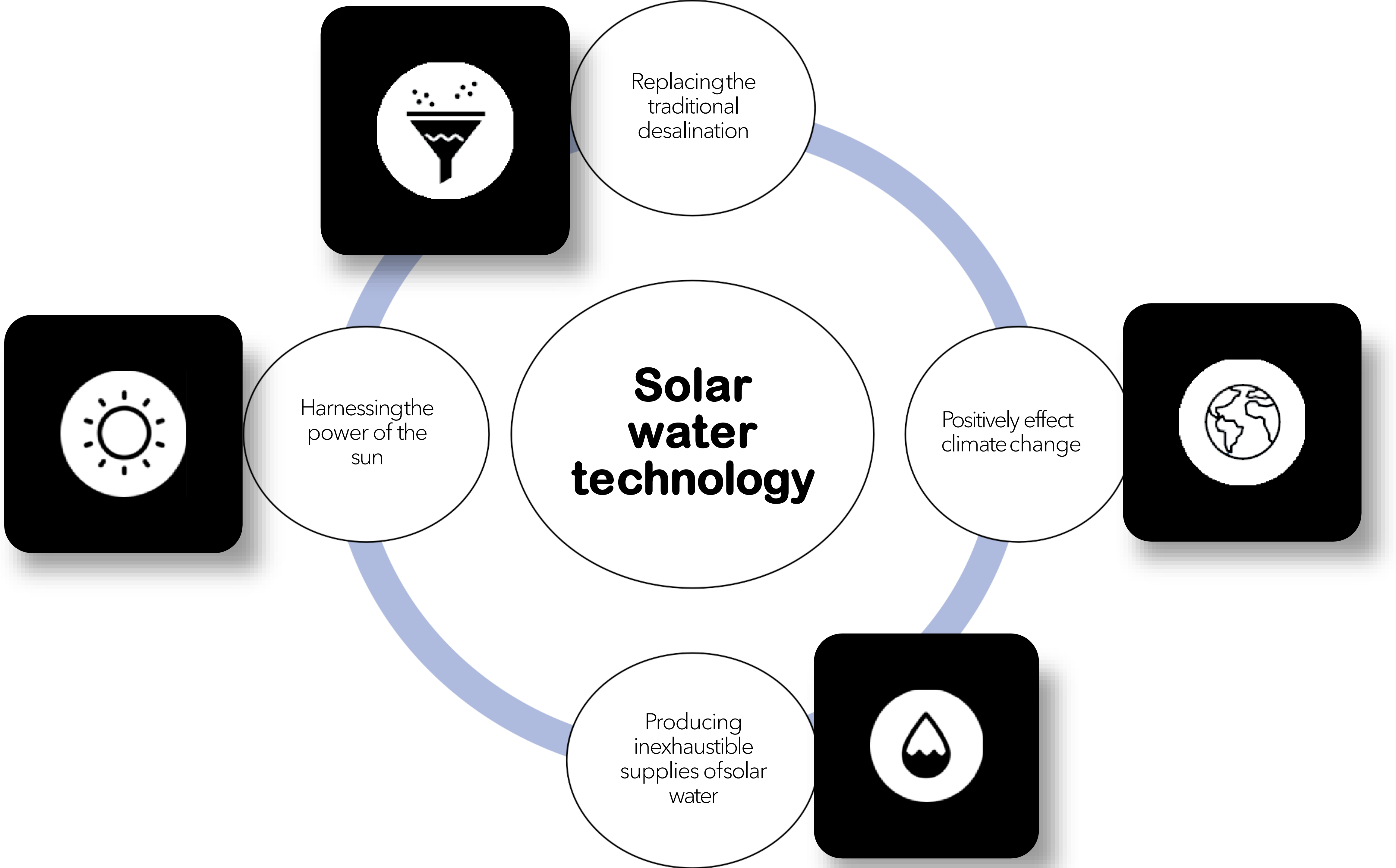
1. SEA WATER INTAKE
2. SOLAR ENERGY CONCENTRATION
3. FROM SEAWATER TO FRESH WATER
4. FRESH SOLAR WATER
5. BRINE PROCESSING



Output Levels of Fresh Solar Water and Salt & Minerals :

The output of fresh water from the Solar Water domes will provide many thousands of cubic meters (millions of liters) of fresh water per day, which is millions of Cubic meters per year (billions of liters).

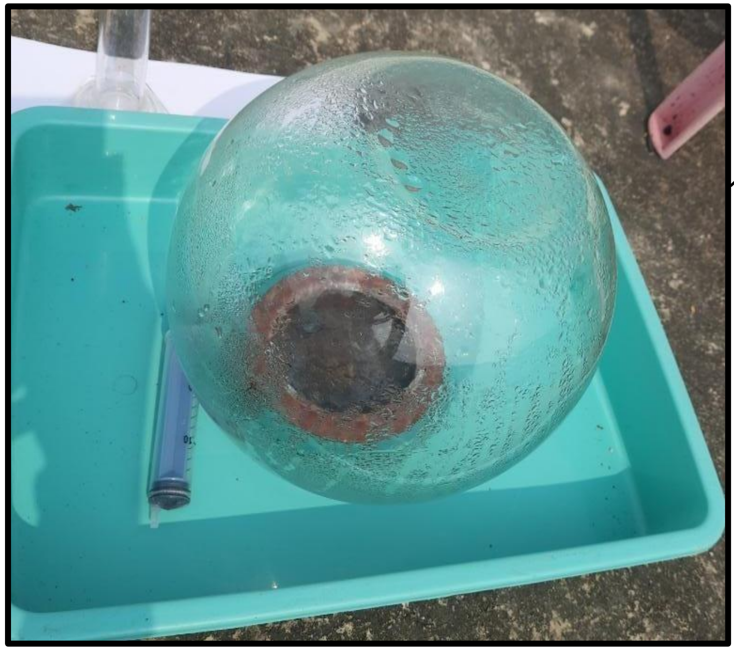
The brine bi-product can be processed to produce high purity salt and other minerals such as high purity Potassium Sulphate, Magnesium Hydroxide and Calcium Carbonate.


Replacing the traditional desalination
Harnessing the power of the sun
Solar water technology
Positively effect climate change
Producing inexhaustible supplies of solar water

1.) Temp -23°c
Time -9:20
Started & V=200ml

2.) Temp -25°c
Time -10:28
1hr :8 minutes after
& V=195 ml left

3.) Temp -26°c
Time -11:30
1hr :10 minutes after
& V=187 ml left



4.) Temp -27°c
Time -12:35
1hr:5 minutes after
& V=179 ml left

5.) Temp-26°c
Time -1:36
1hr:1minutesafter
& V=172 ml left

6.) Temp-26°c
Time- 2:46
1hr:10 minutes after
& V=165 ml left

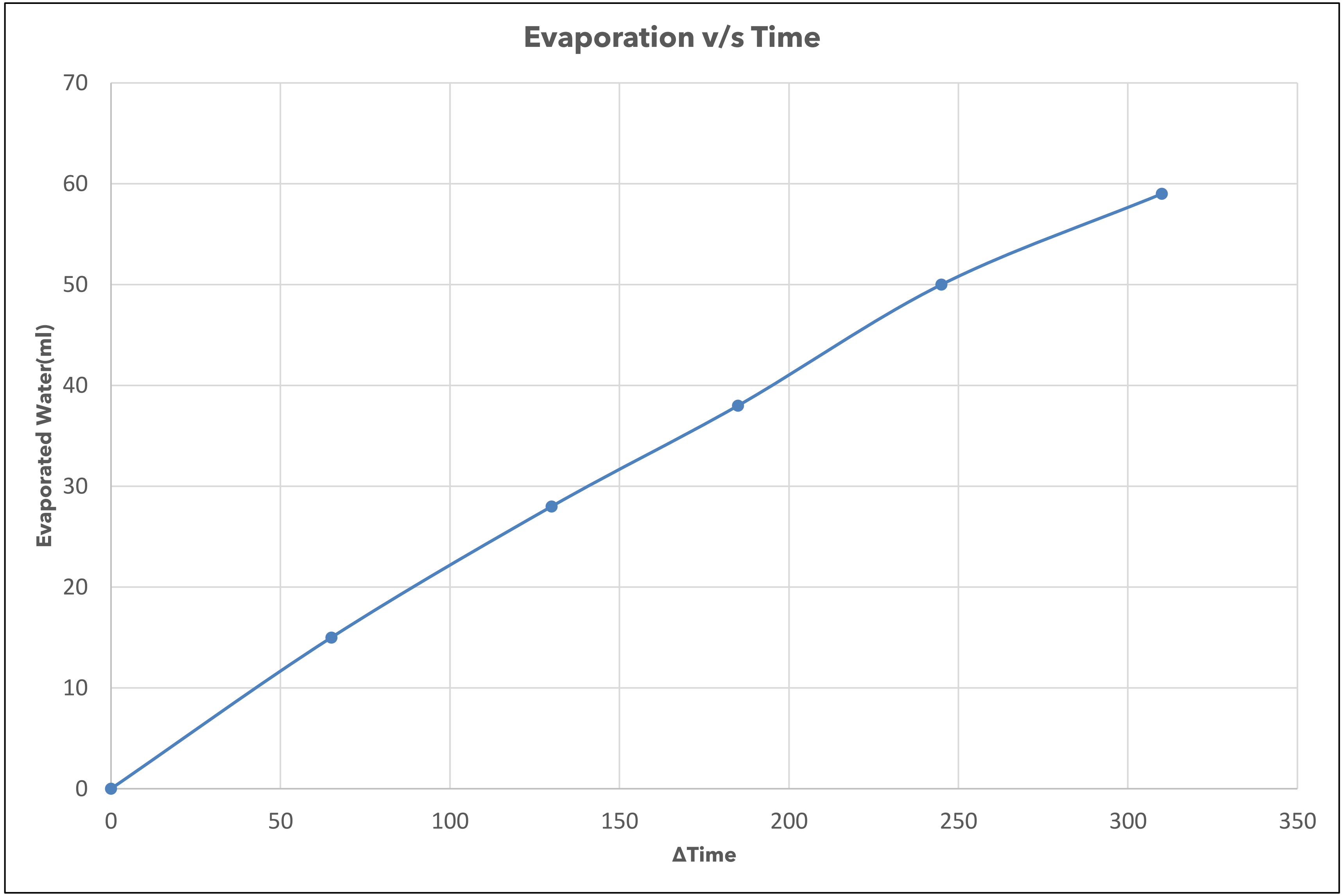
Test Run with Loss Errors :

S.no	Temperature(°c)	Time(hr)	ΔTime	Evaporation	
				Initial value	Final value
1.	25 °c	9:50 am	0 hr	200 ml	200 ml
2.	26 °c	10:55 am	1 hr : 5 min	200 ml	185 ml
3.	28 °c	12:00 am	1 hr : 5 min	185 ml	172 ml
4.	27 °c	12:55 pm	0 hr : 55 min	172 ml	162 ml
5.	27 °c	1:55 pm	1 hr :min	162 ml	150 ml
6.	26 °c	3:00 pm	1 hr : 5 min	150 ml	141 ml

Graph between Evaporated water v/s ΔTime

(Test run with losses):

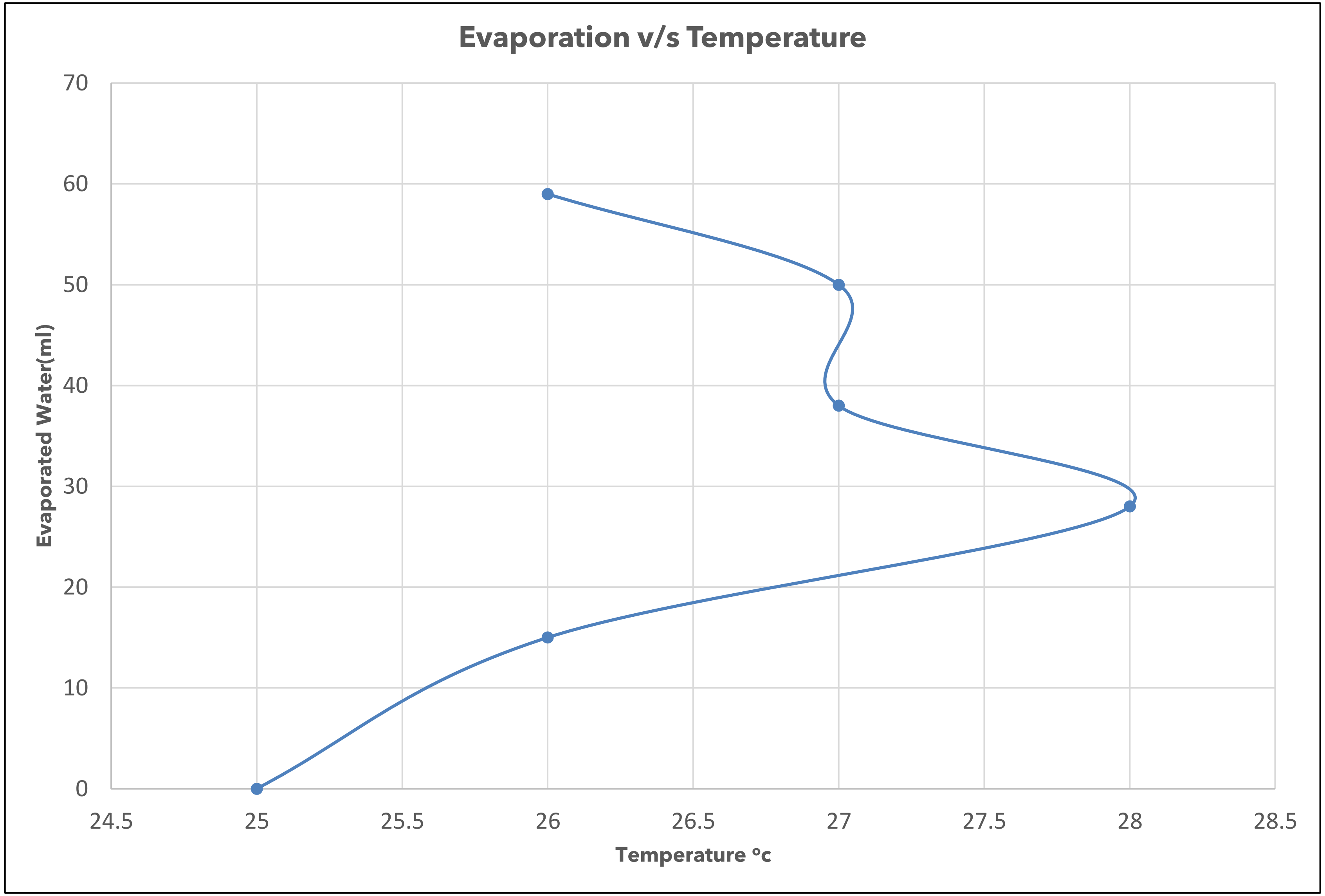
Cumulative Time (min.)	Cumulative Evaporated Water (ml)
0	0
65	15
130	28
185	38
245	50
310	59



Graph between Evaporated water v/s Temperature

(Test run with losses):

Temp (°C)	Cumulative Evaporated Water (ml)
25	0
26	15
28	28
27	38
27	50
26	59



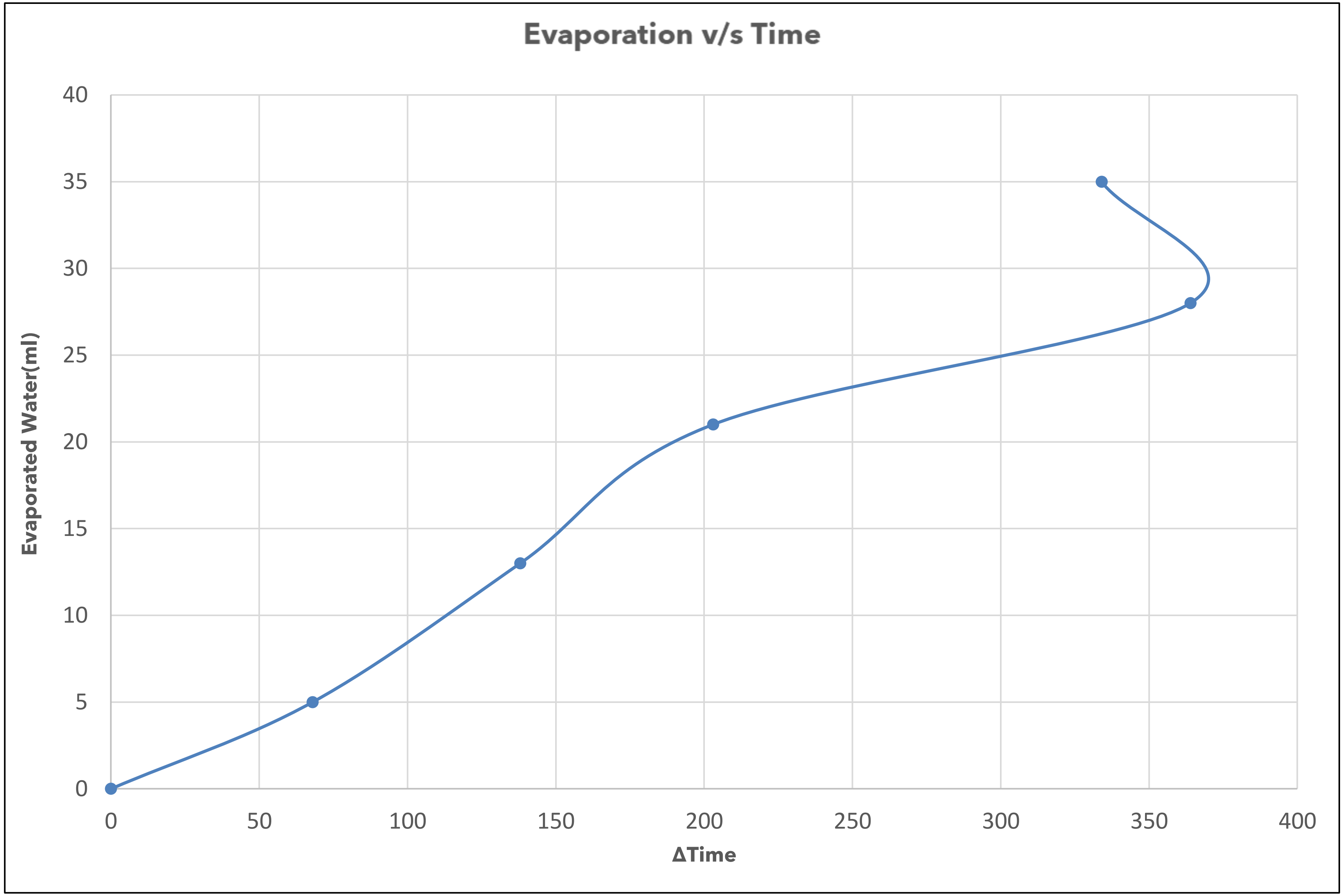
Test Run without Loss Errors :

S.no	Temperature(°c)	Time(hr)	ΔTime	Evaporation	
				Initial value	Final value
1.	23 °c	9:20 am	0 hr	200 ml	200 ml
2.	25 °c	10:28 am	1 hr : 8 min	200 ml	195 ml
3.	26 °c	11:30 am	1 hr : 10 min	195 ml	187 ml
4.	27 °c	12:33 pm	1 hr : 5 min	187 ml	179 ml
5.	26 °c	1:36 pm	1 hr : 1 min	179 ml	172 ml
6.	26 °c	2:46 pm	1 hr : 10 min	172 ml	165 ml

Graph between Evaporated water v/s ΔTime

(Test run without losses):

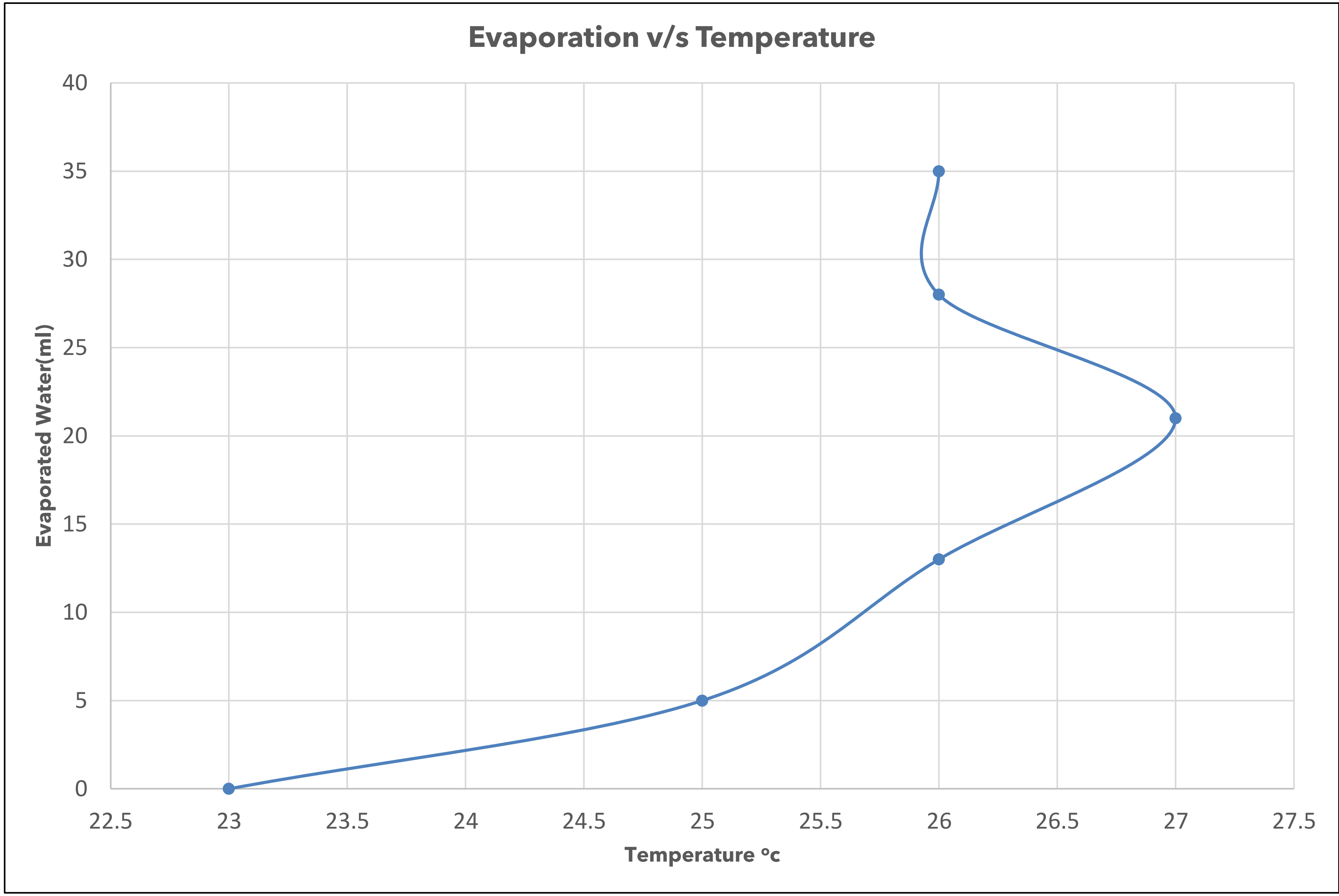
Cumulative Time (min.)	Cumulative Evaporated Water (ml)
0	0
68	5
138	13
203	21
264	28
334	35



Graph between Evaporated water v/s Temperature

(Test run without losses):

Temp (°C)	Cumulative Evaporated Water (ml)
23	0
25	5
26	13
27	21
26	28
26	35



Calculations of Bowl measurements :

- We have taken water in a bowl of hemisphere shape.
- The bowl evaporation surface area is circle
- Bowl top diameter = 8.9 cm

$$Area = \frac{\pi}{4}d^2$$

$$= \frac{\pi}{4}(8.9)^2 cm^2 = 62.21 cm^2 = 6221\ mm^2$$

Basic data to *NOTE* :

- On an average the adult consumes 100 liters/day for various uses such as bathing, washing of clothes, etc.
- And these data varies according to the households, and the areas(urban and rural areas).

Experimental Calculation :

- From our experiment, we conclude that :
- The experiment is done for 326 mins (i.e from 9.20 am to 2.46 pm).
- The water evaporated from a hemispherical bowl of evaporation area of circle 62.21 cm^2 is 35 ml (200ml -165 ml, i.e at 9.20 am - 2.46 pm)
- Now, calculating the amount of water evaporated at this rate per day, is done by considering :

35 ml $\longrightarrow$ 326 min

x ml $\longrightarrow$ 1440 min (24 hours * 60 minutes = per day)

$$x = \frac{35*1440}{326} = 154.601 \text{ ml/day}$$

- Therefore, from our experimentation the rate at which the water evaporates is at 154.601 ml/day
- Now, we try to compare our experimental calculations with the theoretical calculations by considering certain models.

MATHEMATICAL METHODS FOR EVAPORATION RATE

➢ *PENMAN EQUATION :*

- The ***Penman equation*** describes evaporation (*E*) from an open water surface, and was developed by *Howard Penman in 1948*. Penman's equation requires daily mean temperature, wind speed, air pressure, and solar radiation to predict E.

- The Penman formula for the evaporation rate from a lake is simplified to the following:

$$E_0 = \frac{700\ T_m/(100-A)+15(T-T_d)}{(80-T)}\left(\ \mathrm{mm\ day}^{-1}\right)$$

- where $T_m = T + 0.006h$, h is the elevation (meters), T is the mean temperature, A is the latitude (degrees) and T_d is the mean dew-point. The formula applies over a wide range of climates.

Calculation using PENMAN EQUATION:

$$E_o = ((700T_m/(100 - A)) + 15(T - T_d))/(80 - T)$$
$$T_m = T + 0.006h$$

- A=latitude(degrees) =17.922 degrees north(sangivalasa)
- H= 12 m (height ofthe building)
- T=Mean Temperature =$\frac{23+25+26+27+26+26}{6} = 25.5\ centigrade$
- Td =Mean dew point @T=25.5 & Relative Humidity =74.125 %=20.5 centigrade
- Tm=25.5+(0.006*12)=25.572 centigrade (by substituting the values andcalculated)

$$E_o = \frac{((700 * 25.572/(100 - 17.922)) + 15(25.5 - 20.5))}{(80 - 25.5)} = 5.3778\frac{mm}{day}$$
$$E_o = 5.3778 * 6221\frac{mm^3}{day} = 33455.2938\frac{mm^3}{day} = 33.4553\frac{ml}{day}$$

➢ ***ENERGY BALANCE METHOD :***

- It is a potential evaporation defined as quantity of water evaporated per unit area, per unit time from an idealized extensive free water surface under existing atmospheric conditions.

- Potential evaporation of given area varies daily.

- Energy balance method is widely used for estimating the amount of evaporation from a large body of water such as lake, reservoir, etc.

- Evaporation Rate is givenas :

$$E_v = \frac{R_n}{L_v \rho_w}$$

Where,

R_n = Net radiation(W/m^2)
L_v = Latent heat of vaporization(J/Kg)
ρ_w = Water density (Kg/m^3)
E_v = Rate of evaporation(m/s)

Calculation using ENERGY BALANCE METHOD :

$$E_v = \frac{R_n}{L_v \rho_w}$$

- L_v (KJ/Kg) =2500-(263*T∘C)

  T =25 centigrade

  L_v=2500-(263*25)

  =2441 KJ/Kg =2444*1000 J/Kg

- At 25∘C

  R_n =150 W/m^2

- Density is 997 Kg/m^3

- E_v=150/(2441*1000*997) =6.163*10^{-8} m/s

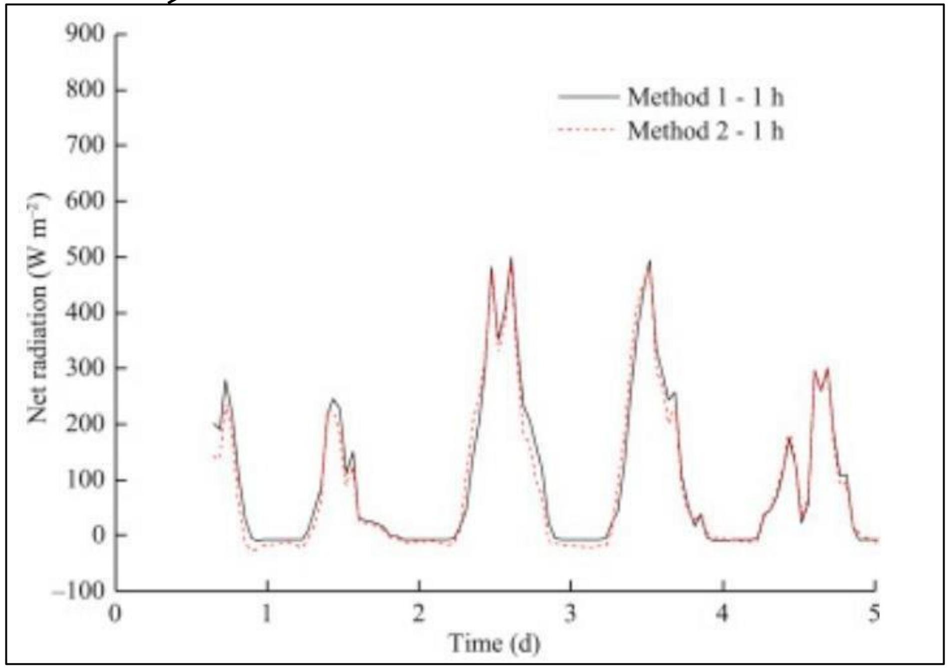
- Conversion of m/s → mm/day

  =6.163*10^{-8}*1000*86400 mm/day

  =5.325 mm/day

$$E_o = 5.325 * 6221 \frac{mm^3}{day} = 33126.825 \frac{mm^3}{day} = 33.1269 \frac{ml}{day}$$

Net radiation v/s Time Data Graph



➢ *CORROSIONPEDIA EXPLAINS EVAPORATION RATE:*

- The easiest way to measure the evaporation rate of a liquid is to record the volume of two points in time and calculate the difference.
- Calculating the evaporation rate by a formula is a less straight forward due to numerous variables. One such formula to determine the evaporation from a swimming pool or similar container under similar conditions is

$$E = \frac{7.4 * P * A * (0.447 * W)^{0.78}}{T + 459.67}$$

Where,

E = Evaporation rate (gallons/day)

A = Surface area (ft^2)

W = speed of air above water (m/hr)

P = Vapor pressure of water at ambient temperature (mmHg)

T = Temperature

- Controlling evaporation is very important in industries where the products are *Thermo-sensitive*
- Examples : Used for mainly Pharma products, coffee extracts and water.

Calculation using CONTROLLING EVAPORATION RATE:

$$E = \frac{7.4 * P * A * (0.447 * W)^{0.78}}{T + 459.67}$$

- P = at 25 °C $\longrightarrow$ 0.0313 atm = 23.788 mmHg
- A = 62.21 cm^2 = 6221 mm^2 = 0.06696 ft^2
- T = 25.5 °C = 77 °F
- W = 769 m/hr

$$E = \frac{7.4 * 23.788 * 0.06696 * (0.447 * 769)^{0.78}}{77 + 459.67} = 2.089\ gallons/day$$

E = 2.089 gallons/day = 2.089*157.73 ml/day = 329.5145 ml/day

INFERENCE :

- As we conducted the experiment, we got the experimental rate of evaporation per day values as 154.601 ml/day
- And Theoretical value from various models are:

  Penman model =33.4553 ml/day Energy balance model=33.1269 ml/day

NOTE :

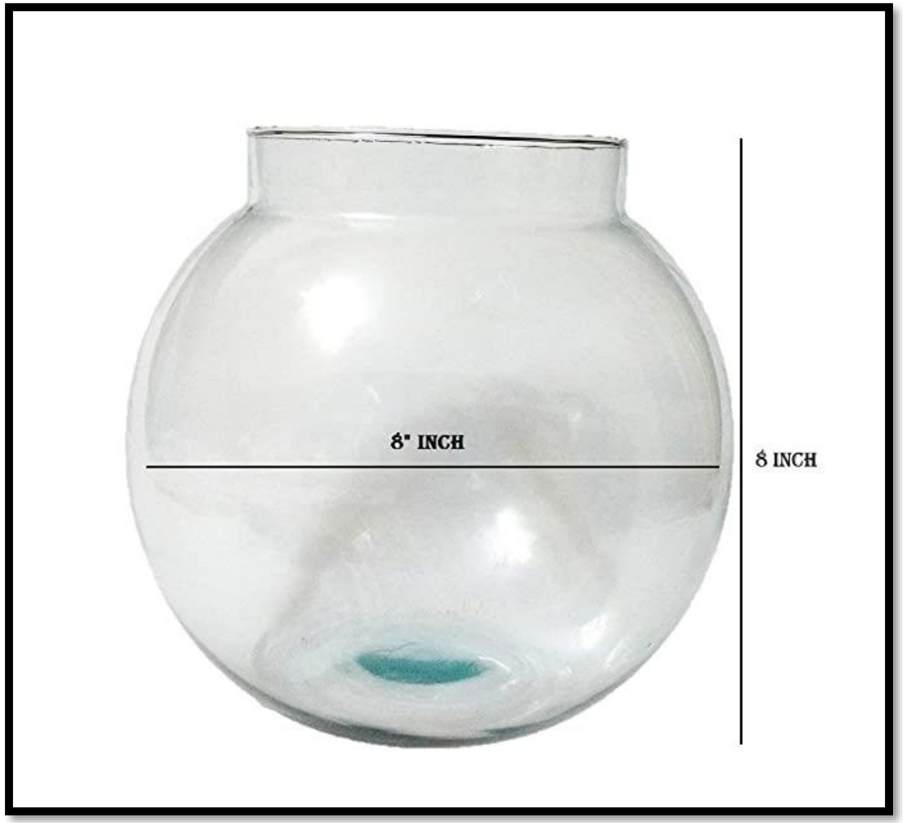
- We had done the experiment using a small bowl which is with a opening of 8.9 cm dia. And covered with a hemisphere glass bowl, and we yield a evaporation result of 154.601 ml/day. If we maximize the bowl to a large tank or on the Sea, our yield would be increased, which would eventually meet the desired water requirement.
- For example, Let us take a tank of 100m diameter(assume a small scale industry).

0.089 m(our bowl) $\longrightarrow$ 154.601 ml/day

for small scaleindustries, 100 m $\longrightarrow$ 173708.9888 ml/day $\longrightarrow$ 173.709 liters/day

Aanalysis on Different Sizes

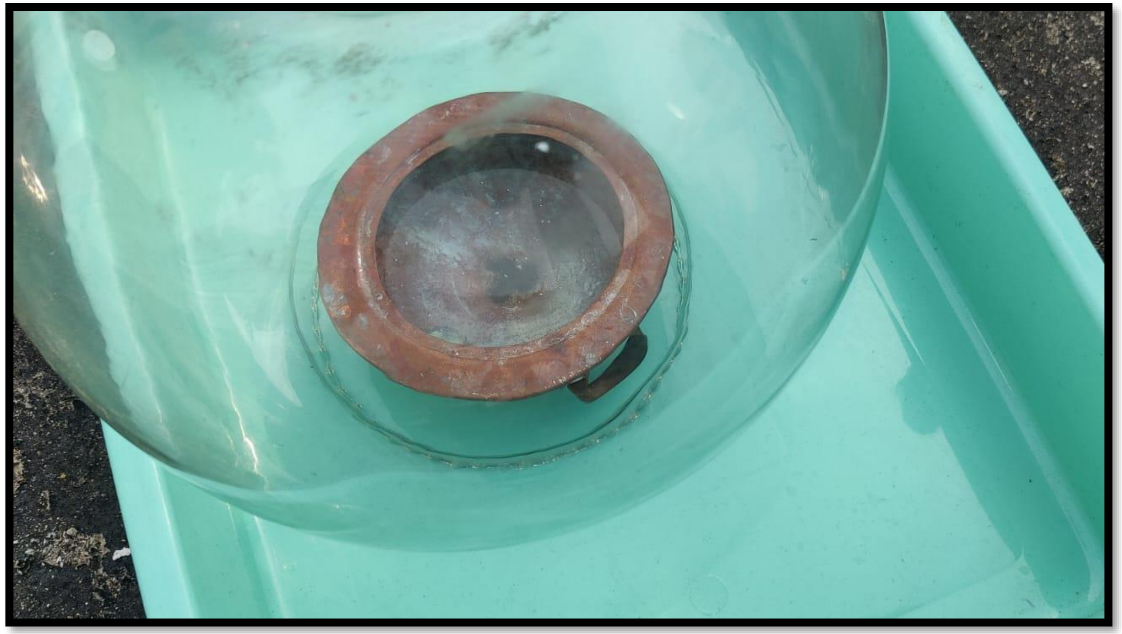
Larger bowl of 10 inches diameter



Smaller bowl of 8 inches diameter

- We have taken 2 glass domes of different sizes, which are of 8 inches in size and 10 inches in size respectively.

- Conducted the evaporation test in a similar setup we had done previously, which is displayed as below



- We compared the evaporation rate from both the spherical domes.

- We conducted the experiment on 17thmarch varying from our previous calculation which was done in the month of December. Which eventually witnessing a change in the time of the year and also indicating a change in the temperature increase.

- We also collected the data which includes the Time, Temperature, Volume.

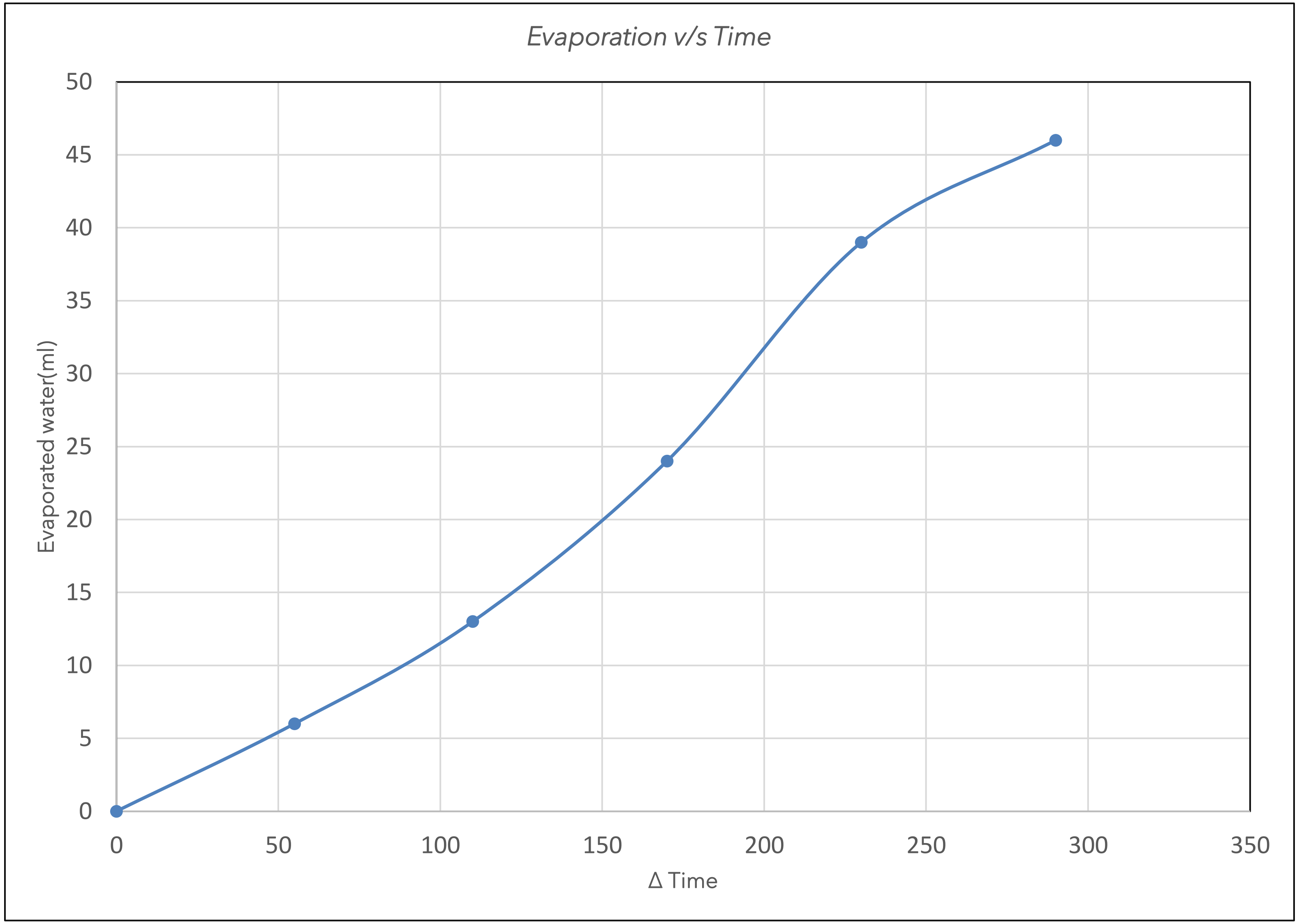
Test Run with Big bowl (10 inches bowl):

S.no	Temperature(°c)	Time(hr)	ΔTime	Evaporation	
				Initial value	Final value
1.	30 °c	9:15 am	0 hr	200 ml	200 ml
2.	31 °c	10:10 am	0 hr : 55 min	200 ml	194 ml
3.	32 °c	11:05 am	0 hr : 55 min	194 ml	187 ml
4.	33 °c	12:05 pm	1 hour	187 ml	176 ml
5.	34 °c	1:05 pm	1 hour	176 ml	161 ml
6.	33 °c	2:05 pm	1 hour	161 ml	154 ml

Graph between Evaporated water v/s ΔTime

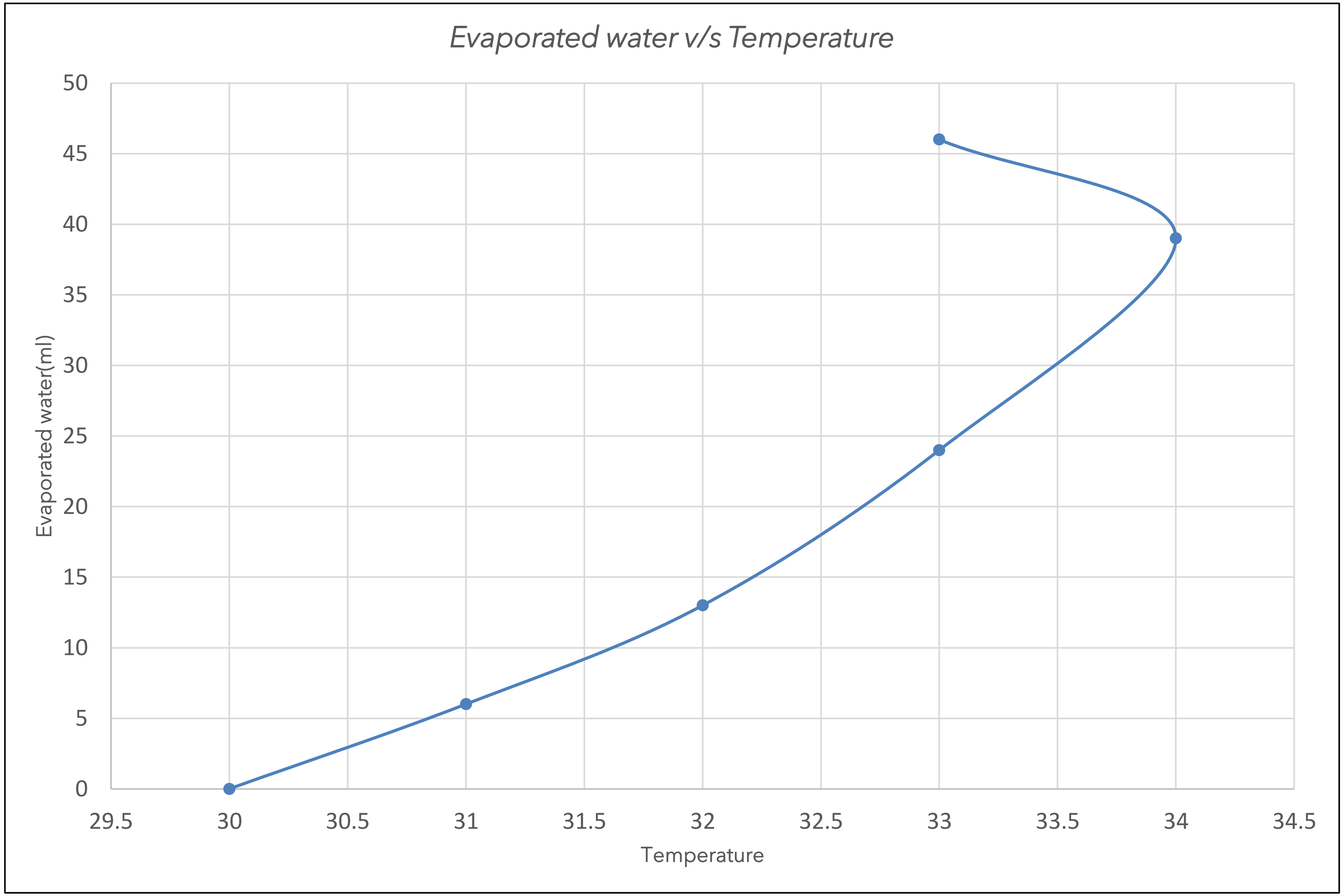
(10 inches bowl) :

Cumulative Time (min.)	Cumulative Evaporated Water (ml)
0	0
55	6
110	13
170	24
230	39
290	46



Graph between Evaporated water v/s Temperature
(10 inches bowl) :

Temp (°C)	Cumulative Evaporated Water (ml)
30	0
31	6
32	13
33	24
34	39
33	46



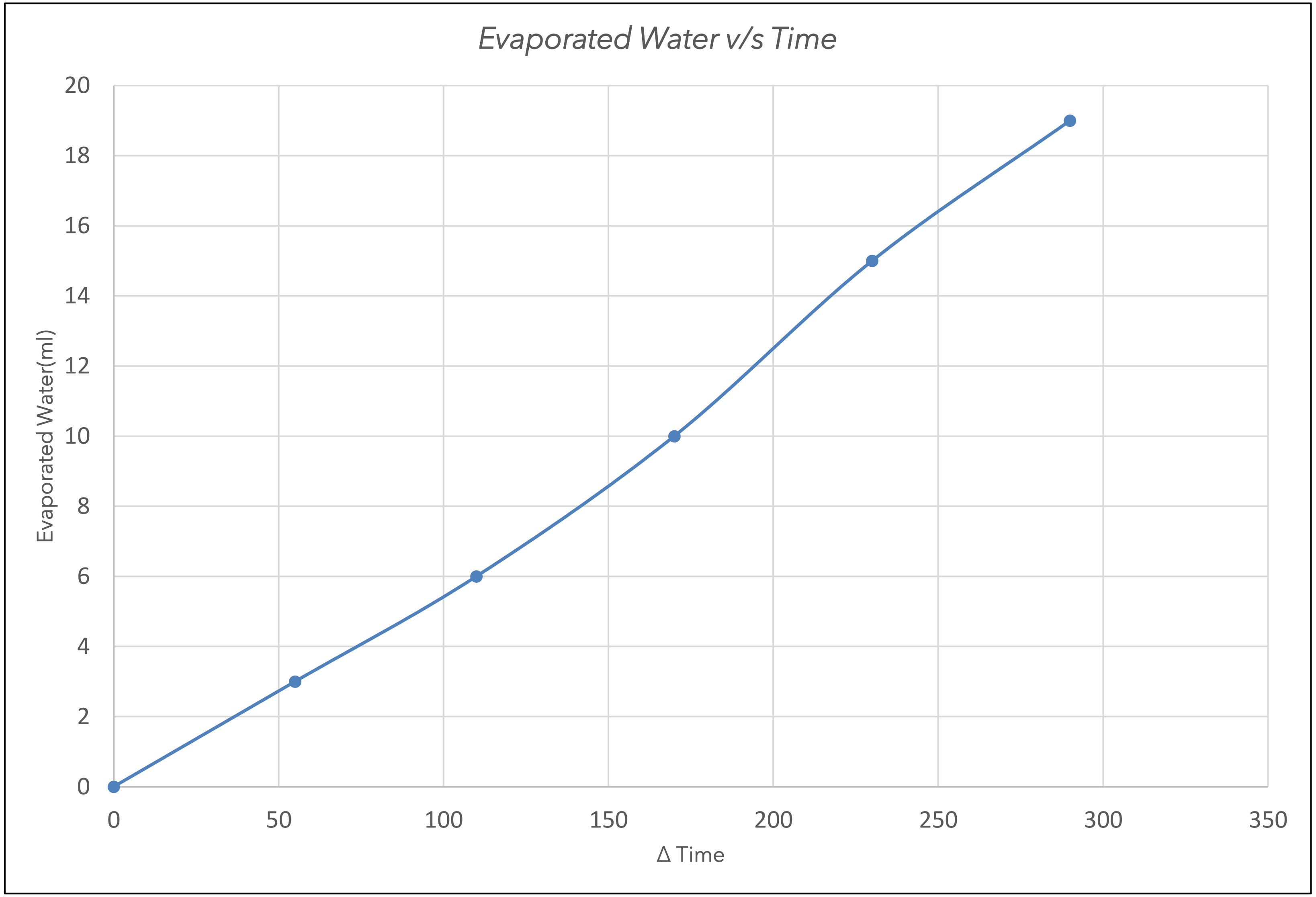
Test Run with Small bowl (8 inches bowl):

S.no	Temperature(°c)	Time(hr)	ΔTime	Evaporation	
				Initial value	Final value
1.	30 °c	9:15 am	0 hr	100 ml	100 ml
2.	31 °c	10:10 am	0 hr : 55 min	100 ml	97 ml
3.	32 °c	11:05 am	0 hr : 55 min	97 ml	94 ml
4.	33 °c	12:05 pm	1 hour	94 ml	90 ml
5.	34 °c	1:05 pm	1 hour	90 ml	85 ml
6.	33 °c	2:05 pm	1 hour	85 ml	81 ml

Graph between Evaporated water v/s ΔTime

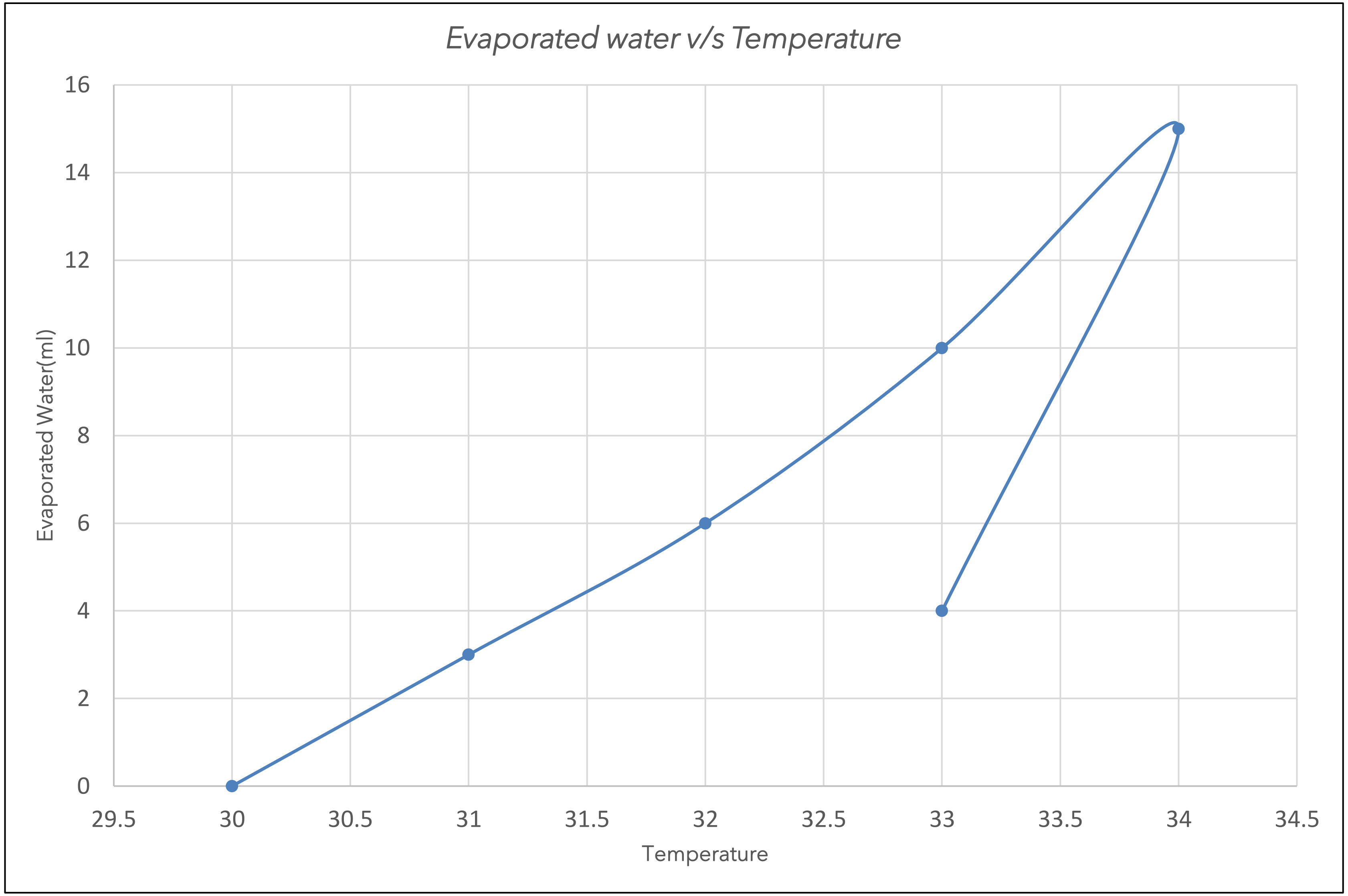
(8 inches bowl) :

Cumulative Time (min.)	Cumulative Evaporated Water (ml)
0	0
55	3
110	6
170	10
230	15
290	19



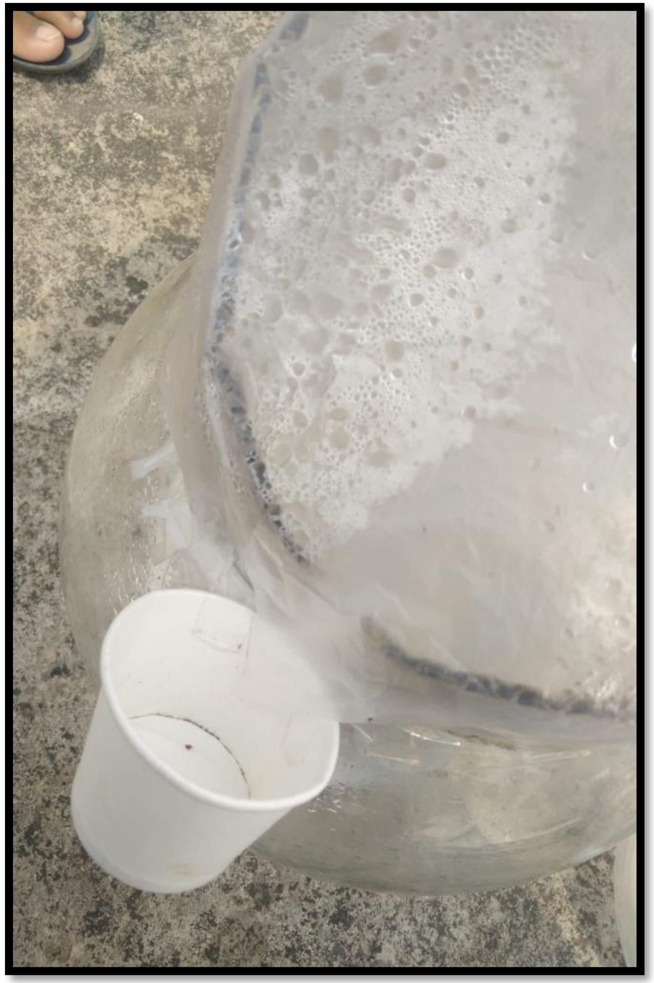
Graph between Evaporated water v/s Temperature
(8 inches bowl) :

Temp (°C)	Cumulative Evaporated Water (ml)
30	0
31	3
32	6
33	10
34	15
33	19



Working Designs :

Design 1 : Non – Removable Cover



- The design-1 was prepared by using a plastic cover, which acts as a lid & a structure made from cardboard which supports the plastic cover.

- The lid was placed in a slanting way so the water which gets evaporated was been collected by condensation at the top on the surface of the plastic cover.

- The collected water was been sent down into a paper cup which eventually gives us pure evaporated water

- Experiment by the design-1 was done from 10.00 am in the morning till 2.30 pm in the afternoon. We noted the readings after a fixed time interval, without interfering in the evaporation, which is similar to the **batch process** of collection of data.

	Temperature	Time	Volume in bowl
Initial readings	31°c	10.00 am	300 ml
Final readings	33°c	2.30 pm	256 ml

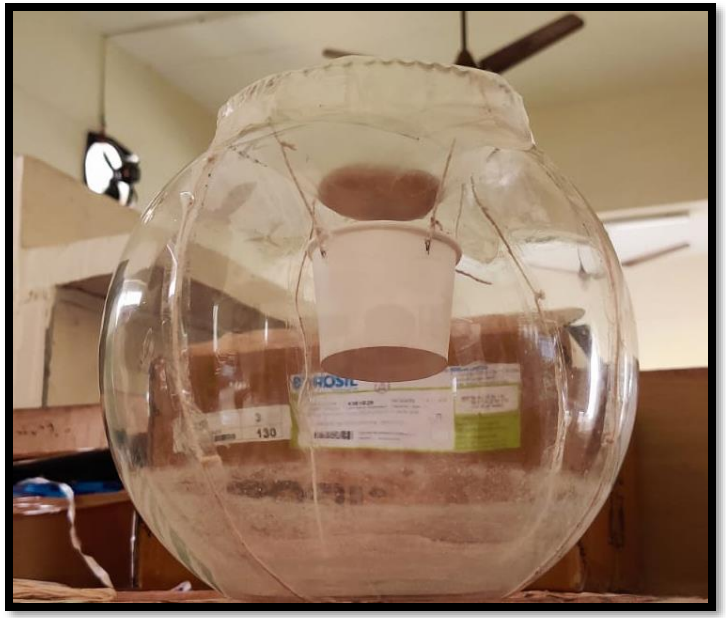
Design 2 : Removable Cover

- The design-2 was prepared with the same material which was been used in the design-1.
- And the design-2 adjustments and the method of orientation also similar to the design-1, but the main difference is we made the lid to be removable and not be fixed.
- So, we could collect the data for certain time intervals. Which is similar to continuous model of collection of data.

- Experiment by the design-2 was done from 11.30 am in the morning till 2.50 pm in the afternoon.

Temperature	Time	Volume in bowl	Volume in cup
31^{o}c	11.30 am	300 ml	0 ml
32^{o}c	12.30 pm	294 ml	0 ml
31^{o}c	1.35 pm	273 ml	1 ml
31^{o}c	2.50 pm	261 ml	2 ml

Design 3 : Hanging cup covered with transparent plastic cover



- The design-3 was prepared by using a plastic cover, which acts as a lid & a stone which was been placed on the plastic cover and a paper cup for collection for evaporated water.
- We had made a simple idea of making a loosely attested plastic cover as the top surface.
- And we have kept a paper cup by hanging it with thread beneath the cover, and as we placed the stone on the top it made a inverted conical structure which helps in collecting the evaporated water to be condensed at the top on the cover and been collected into the paper cup.
- This whole mechanism is clearly portrayed below



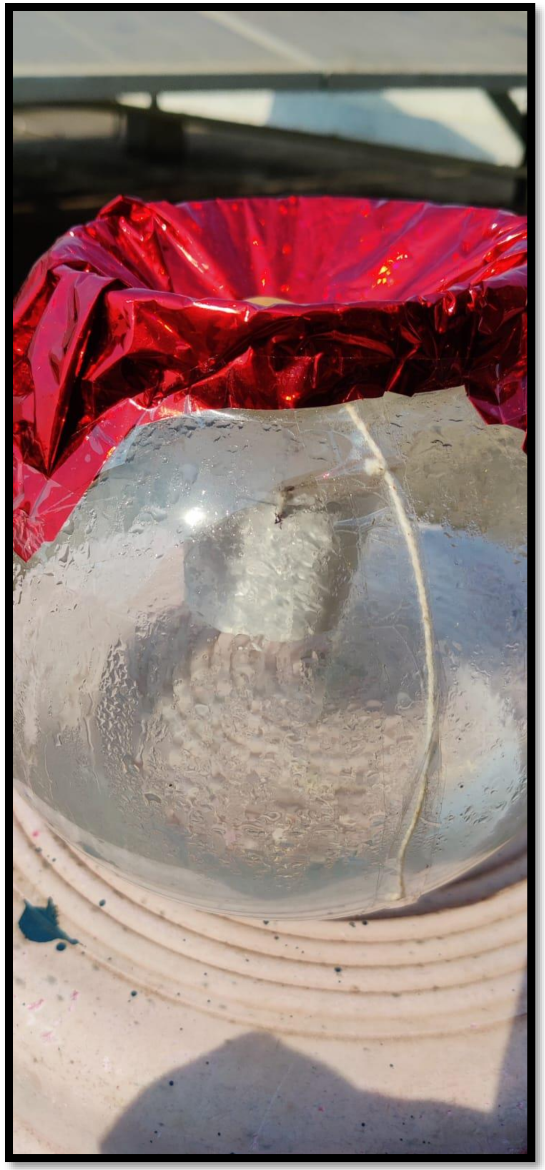

- By, this method we have collected a good amount of water in the paper cup. Nearly about 8 ml was been collected into the paper cup.

- Experiment by the design-3 was done from 9.05 am in the morning till 2.45 pm in the afternoon.

- This experiment was also done in the closed atmosphere, i.e. without disturbing the apparatus and collecting the data only after a defined time period .

	Temperature	Volume in bowl	Volume in cup	Time
Initial readings	29^{o}c	300 ml	0 ml	9.05 am
Final readings	34^{o}c	256 ml	8 ml	2.45 pm

Design 4 : Hanging cup covered with opaque plastic cover



- The design-4 was prepared with the same material which was been used in the design-3. But a opaque cover which completely blocks the light from the top.

- This design was investigated because of the material that we took to cover the top was a opaque material (to be precise, a gift wrapping cover) which has a smooth surface compared to polythene plastic cover which has a rough surface though it is a transparent one.

- The preliminary idea was due to the smoothness as the condensed droplets at the top would easily be collected into the paper cup.

- The experiment had done from 10.40 am to 2.40 pm and below is the experimental reading we collected.

- There was no water collected in the paper cup.

	Temperature	Time	Volume in bowl
Initial reading	$31^{o}c$	10.40 am	300 ml
Final reading	$34^{o}c$	2.40 pm	280 ml

Design 5 : The Straw collection method

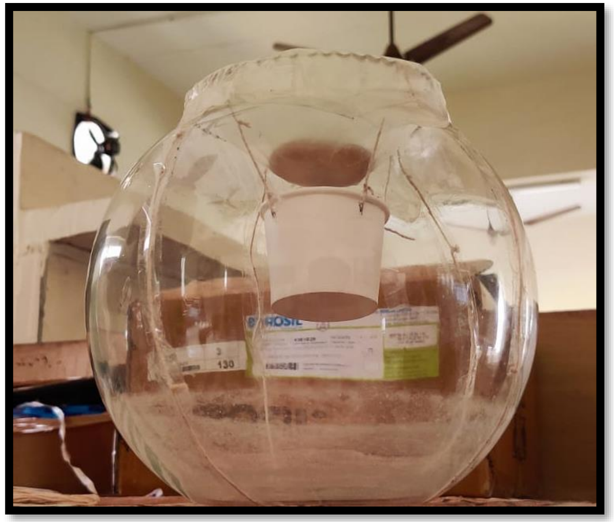
- The design-5 was prepared by using a simple plastic straw for collection.
- The plastic straws were attached inside the inverted spherical dome which acts for collecting the evaporated water.
- From the inverted dome, the water which was collected at the top was been condensed and the been slide through the walls of the dome.
- The falling water droplets been collected inside the straws and due to the inclined down setup of the design-5, the water been collected at the bottom into a collecting vessel at the bottom.
- The data of this design-5 is:

	Temperature	Time	Volume in bowl
Initial reading	31°c	10.00 am	300 ml
Final reading	32°c	2.55 pm	295ml

- Here, in this model we have not received any of the water in the plastic straws.
- We could only see a few moist droplets in the plastic straw surface.

Final Selection of Model :

- We have come to a conclusion on selecting Hanging cup model.
- As, we could get a maximized yield in that model compared to others.



Working Model	Temperature ($^{\circ}$c)	Time Duration (min.)	Volume Collected (ml)
Non Removable Cover method	31°c to 33°c	240 minutes	1 ml
Removable Cover method	31°c to 32°c	200 minutes	2 ml
Hanging Cup (transparent Cover) method	29°c to 34°c	340 minutes	8 ml
Hanging Cup (opaque Cover) method	31°c to 34°c	240 minutes	0 ml
Straw Collection method	31°c to 32°c	295 minutes	0 ml

Experimentation with Salt Water :

- We have conducted the experimentation with salt water.
- Firstly, we prepared a salt water which is near to the salt concentration in the oceans.
- Which is about 1M Nacl concentration in oceans.

➢ Experimentation with the Small Bowl :

- We have prepared 250 ml of salt water by taking 14.63 grams of salt to get 1M of Nacl solution.

Initial Reading
Volume taken in the bowl : 200ml
Time : 9:50 am
Temperature 33^{o}c

Final Reading
Volume collected in the Cup : 3ml
Time : 2:10 pm
Temperature 34^{o}c

- We have conducted for a duration of 240 minutes.

- We collected about 3 ml in the cup, which gives us the pure water.

➢ Experimentation with the Large Bowl :

- On the same note as like the small bowl, we prepared 250 ml of salt water with 14.63 gm of salt in it to makeup 1M Nacl solution.

Initial Reading
Volume taken in the bowl : 200ml
Time : 9:52 am
Temperature 32°c

→

Final Reading
Volume collected in the Cup : 5ml
Time : 2:00 pm
Temperature 34°c

- We have conducted for a duration of 248 minutes.
- We collected about 5 ml in the cup, which gives us the pure water.

- *Our understandings basing the experimentation of salt water of 200 ml in both the bowls are:*

Bowl Size	Initial Volume	Collected Volume	ΔTime	ΔTemperature $^{\circ}$c
Larger Bowl	*200 ml*	*5 ml*	*248 minutes*	*2°c*
Smaller Bowl	*200 ml*	*3 ml*	*240 minutes*	*1°c*

➢ Experimentation with water filled half of the bowl :

- We had done the experiment by filling the bowl to half, to implement an idea of increasing the surface area.

- Since, for a sphere the surface area is maximum at the centre.

- We taken larger bowl, which required about 3.5 litres of salt water to reach half of it's level.

Initial Reading
Volume taken in the bowl : 3.5 litres
Time : 9:05 am
Temperature 32°c

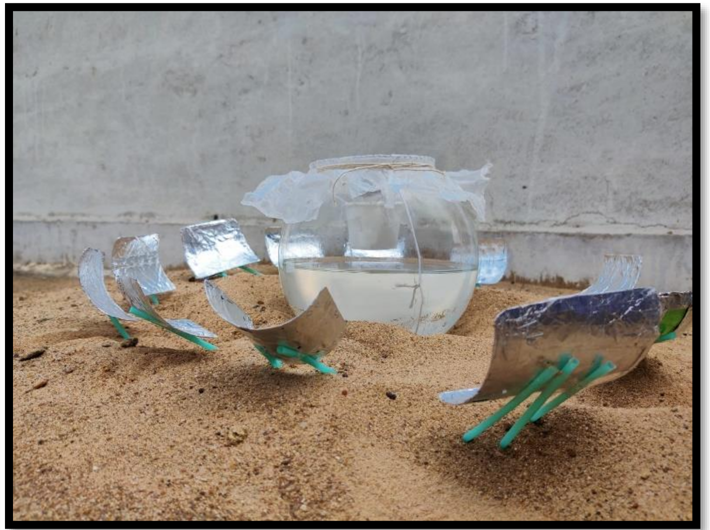
Final Reading
Volume collected in the Cup : 4ml
Time : 2:30 pm
Temperature 33°c

- We conducted the experiment in a time duration of 325 minutes.
- Only 4 ml of water is collected in the cup.
- We overcome a cloudy weather during this experimentation, due to which we think our desired yield maybe decreased.

- *And also a doubtful thought raised during our observation, maybe increase in the volume had decreased the yield, because the water increased the amount of water to be heated eventually increased so the evaporation rate might be decreased.*

➢ Experimentation by placing Aluminum solar concentrators :

- We have taken small bowl and eventually filled the bowl to half of the level, which is about 1.5 liters.
- And the temperature of the experiment day was 32°c to 33°c and a cloudy weather was there.
- Time of start of the experimentation was 10.00 am to 2.30 pm, which is of a duration of 270 minutes.



Initial Reading
Volume taken in the bowl : 1.5 litres
Time : 10:00 am
Temperature 32°c

→

Final Reading
Volume collected in the Cup : 4ml
Time : 2:30 pm
Temperature 33°c

- When we conducted the experiment by filling 200 ml of water in the small bowl water collected is 3 ml and now when we filled half of the bowl and kept solar concentrators we collected 3 ml only but on a cloudy day compared to 200 ml experimentation day.

Experimental Calculations (Amount of water collected):

- *Small Bowl (normally placed) :*

3 ml → 240 min
x ml → 720 min (12 hours daylight * 60 minutes)

$x = \frac{3*720}{240} = 9$ ml/day

- *Large Bowl (normally placed) :*

5 ml → 248 min
x ml → 720 min (12 hours daylight * 60 minutes)

$x = \frac{5*720}{248} = 14.5$ ml/day

- *Large Bowl (half filled) :*

4 ml → 325 min
x ml → 720 min (12 hours daylight * 60 minutes)

$x = \frac{4*720}{325} = 8.9$ ml/day

- *Small Bowl (half filled with aluminum solar concentrators placed) :*

4 ml → 270 min
x ml → 720 min (12 hours daylight * 60 minutes)

$x = \frac{4*720}{270} = 10.67$ ml/day

Volume taken = 200ml
Maximum temperature reached on the day is 34°c and a bright sunny day

Volume taken = 3500 ml

Weather on these days is cloudy and the maximum temperature reached on these days is 33°c only

Volume taken = 1500 ml

Theoretical Calculations :

- *Small Bowl (half filled with aluminum solar concentrators placed) :*

  Initial water taken in 8 inches bowl = 1500 ml
  Water collected in cup = 4ml
  Final water present in 8 inches bowl = 1465 ml

  Lowest temperature recorded during the experimentation = 32^{o}c
  Highest temperature recorded during the experimentation = 33^{o}c
  Mean temperature = 32.5^{o}c

- The Penman formula for the evaporation rate from a lake is simplified to the following:

$$E_0 = \frac{700\ T_m/(100-A)+15(T-T_d)}{(80-T)}(\text{ mm day}^{-1})$$

- where $T_m = T + 0.006h$, h is the elevation (meters), T is the mean temperature, A is the latitude (degrees) and T_d is the mean dew-point. The formula applies over a wide range of climates.

Calculation using PENMAN EQUATION:

$$E_o = ((700T_m/(100 - A)) + 15(T - T_d))/(80 - T)$$
$$T_m = T + 0.006h$$

- A=latitude(degrees) =17.922 degrees north(sangivalasa)
- H= 12 m (height ofthe building)
- T=Mean Temperature = $\frac{32+33}{2}$ = 32.5°c
- Td =Mean dew point@T=32.5& Relative Humidity=60 %=25 centigrade
- Tm=32.5+(0.006*12)=32.572 centigrade (by substituting the values andcalculated)

$$E_o = \frac{((700 * \frac{32.572}{100 - 17.922} + 15 * (32.5 - 25))}{(80 - 32.5)} = 8.217 \frac{mm}{day}$$

$$E_o = 8.217 * 324.29 \frac{mm^3}{day} = 266469.09 \frac{mm^3}{day} = 266.469 \frac{ml}{day}$$

Theoretical Calculations :

- *Large Bowl (normally placed) :*

  Initial water taken in 10 inches bowl = 200 ml
  Water collected in cup = 5ml
  Final water present in 10 inches bowl = 145 ml

  Lowest temperature recorded during the experimentation = 32°c
  Highest temperature recorded during the experimentation = 34°c
  Mean temperature = 33°c

- The Penman formula for the evaporation rate from a lake is simplified to the following:

$$E_0 = \frac{700\ T_m/(100-A)+15(T-T_d)}{(80-T)}(\ \mathrm{mm\ day}^{-1})$$

- where $T_m = T + 0.006h$, h is the elevation (meters), T is the mean temperature, A is the latitude (degrees) and T_d is the mean dew-point. The formula applies over a wide range of climates.

Calculation using PENMAN EQUATION:

$$E_o = ((700T_m/(100 - A)) + 15(T - T_d))/(80 - T)$$
$$T_m = T + 0.006h$$

- A=latitude(degrees) =17.922 degrees north(sangivalasa)
- H= 12 m (height ofthe building)
- T=Mean Temperature = $\frac{32+34}{2}$ = 33°c
- Td =Mean dew point@T=33& Relative Humidity=60 %=25.5centigrade
- Tm=33+(0.006*12)=33.072 centigrade (by substituting the values and calculated)

$$E_o = \frac{((700 * \frac{33.072}{100 - 17.922} + 15 * (33 - 25.5))}{(80 - 33)} = 8.39\frac{mm}{day}$$

$$E_o = 8.39 * 8103.2096\frac{mm^3}{day} = 67985.93\frac{mm^3}{day} = 67.985\frac{ml}{day}$$

➢ Experimentation by placing Reflecting Mirrors :

- We have taken both the bowls and eventually filled the bowl to half of the level, which is about 1.5 liters and 3.5 liters respectively..
- And the temperature of the experiment day was 33°c to 34°c and a good sunny weather was there.
- Time of start of the experimentation was 9.50 am to 2.40 pm, which is of a duration of 290 minutes.

- We have clearly see the results from the eventually, in our final model we have maximized the collection of water apart from the previous model of aluminium concentrators.
- Also, we conducted the necessary calculations as we done previously.

	Small Bowl	Large Bowl
Initial Temperature	33°c	33°c
Initial Time	9:50 am	9:55 am
Initial volume in bowl	1500 ml	3500 ml
Final Temperature	34°c	34°c
Final Time	2:40 pm	2:45 pm
Final volume in bowl	1442 ml	3428 ml
Volume collected in cup	7 ml	10 ml

Final Calculations :

- We have performed the final conclusive calculations, the evaporation rates for the designs by theoretically using *penman equation & Energy balance method,* and experimentally from the obtained data.

- **DESIGN-1:**
- The data for the design 1 is

	Temperature	Time	Volume in bowl
Initial readings	31°c	10.00 am	300 ml
Final readings	33°c	2.30 pm	256 ml

- *Calculation by Penman Equation*

$$\boldsymbol{E_o = ((700T_m/(100 - A)) + 15(T - T_d))/(80 - T)}$$

$$\boldsymbol{T_m = T + 0.006h}$$

- A=latitude(degrees) =17.922 degrees north(sangivalasa)
- H= 12 m(height ofthe building)
- T=Mean Temperature = $\frac{31+33}{2}$ = 32°c
- Td = Mean dew point @T=32°c & Relative Humidity =60 % = 24.6°c
- Tm=32+(0.006*12) =32.072 centigrade (by substituting the values andcalculated)

$$E_o = \frac{((700 * \frac{32.072}{100 - 17.922} + 15 * (32 - 24.6))}{(80 - 32)} = 8.011 \frac{mm}{day}$$

$$E_o = 8.011 * 50670 \frac{mm^3}{day} = 405.917 \frac{mm^3}{day} = 405 \frac{ml}{day}$$

- *Calculation by Energy Balance method :*

$$\boldsymbol{E_v} = \frac{\boldsymbol{R_n}}{\boldsymbol{L_v \rho_w}}$$

- $\boldsymbol{L}$ (KJ/Kg) =2500 - (2.36 * T°c)

  T =32°c

  L_v=2500-(2.36*32°c)

  =2424.5 KJ/Kg

- At 32°C

  R_n =190 W/m²

- Density is 997 Kg/m³

- E_v=190/(2424.5*997) =7.86*10⁻⁸ m/s

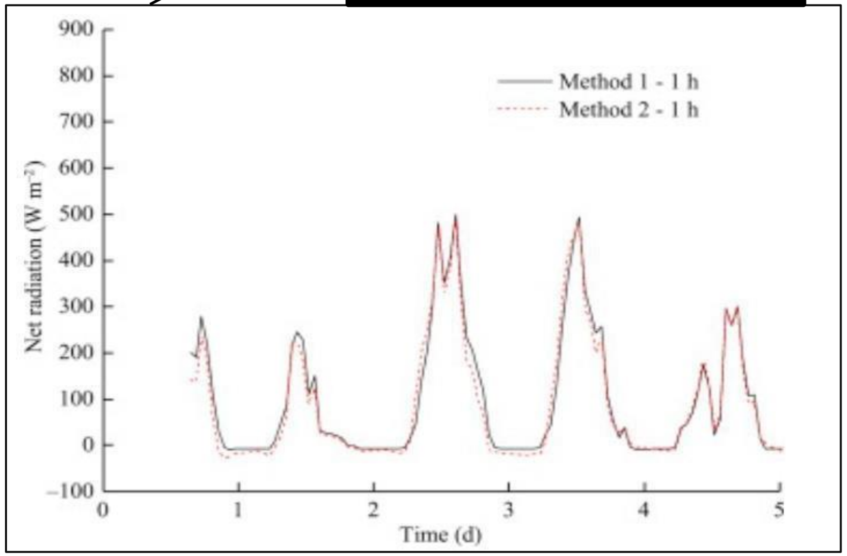
- Conversion of m/s → mm/day

  =47.86*10⁻⁸*86400*1000 mm/day

  =6.79 mm/day

- $\boldsymbol{E_o} = 6.79 * 50670 \frac{mm^3}{day} = 344.11 \frac{ml}{day}$

Net radiation v/s Time Data Graph



Volume taken = 300 ml

- *Calculation by Experimental method:*

44 ml $\longrightarrow$ *240 minutes*

X ml $\longrightarrow$ *1440 minutes*

*X = (1440*44)/240 = 264 ml/day*

Temperature inlet: 31^{o}c
Temperature outlet: 33^{o}c

Properties		Design 1	Design 2	Design 3	Design 4	Design 5
Temperature	*Initial Reading*	31°c	31°c	29°c	31°c	31°c
	Final Reading	33°c	31°c	34°c	34°c	32°c
Size		*Big bowl*	*Big bowl*	*Small bowl*	*Small bowl*	*Big bowl*
Time	*Initial Reading*	10:00 am	11:30 am	9:05 am	10:40 am	10:00 am
	Final Reading	2:30 pm	2:50 pm	2:45 am	2:40 pm	2:55 pm
Volume in bowl	*Initial Reading*	300 ml	300 ml	300 ml	300 ml	300 ml
	Final Reading	265 ml	261 ml	256 ml	280 ml	295 ml
Theoretical calculations	*Penman Equation*	405 ml/day	392 ml/day	254 ml/day	266 ml/day	397 ml/day
	Energy balance Equation	344 ml/day	343.8 ml/day	220 ml/day	220 ml/day	344 ml/day
Experimental calculations		264 ml/day	281 ml/day	186 ml/day	120 ml/day	24 ml/day
Theoretical-Experimental	*Penman-Exp.*	141 ml/day	112 ml/day	68 ml/day	146 ml/day	372 ml/day
	Energy-Exp.	80 ml/day	63 ml/day	34 ml/day	100 ml/day	318 ml/day
Error %	*(Penman-Exp.)/Exp.*	53.41%	39.86%	36.56%	121.67%	1550%
	(Energy-Exp.)/Exp.	30.30%	22.42%	18.28%	83.33%	1325%

Properties		D1: Normally Placed		D2: Al. concentrators		D3: Reflecting Mirrors	
Temperature	*Initial Reading*	33°c	32°c	32°c	32°c	33°c	33°c
	Final Reading	34°c	34°c	33°c	33°c	34°c	34°c
Size		**SMALL BOWL**	**LARGE BOWL**	**SMALL BOWL**	**LARGE BOWL**	**SMALL BOWL**	**LARGE BOWL**
Time	*Initial Reading*	10:00 am	9:52 am	10:00 am	10:05 am	9:50 am	9:55 am
	Final Reading	2:30 pm	2:00 pm	2:30 pm	2:35 pm	2:40 am	2:45 am
Volume in bowl	*Initial Reading*	200 ml	200 ml	1500 ml	3500 ml	1500 ml	3500 ml
	Final Reading	175 ml	150 ml	1465 ml	3450 ml	1458 ml	3435 ml
Theoretical calculations	*Penman Equation*	278 ml/day	425 ml/day	266 ml/day	416 ml/day	278 ml/day	434 ml/day
	Energy balance Equation	220.53 ml/day	344 ml/day	220 ml/day	344 ml/day	221 ml/day	344 ml/day
Experimental calculations		145 ml/day	277 ml/day	166 ml/day	238 ml/day	208 ml/day	323 ml/day
Theoretical-Experimental	*Penman-Exp.*	133 ml/day	148 ml/day	60 ml/day	178 ml/day	70 ml/day	111 ml/day
	Energy-Exp.	87 ml/day	67 ml/day	54 ml/day	106 ml/day	13 ml/day	21 ml/day
Error %	*(Penman-Exp.)/Exp.*	91.72%	53.43%	36.14%	74.79%	33.65%	34.36 %
	(Energy-Exp.)/Exp.	60%	24.19%	32.53%	44.54%	6.25 %	6.50 %

Conclusions:

To conclude, we want to desalinate sea water by using solar energy and for that we designed many models and each model has its advantages and disadvantages from observing these models some are inefficient because of small set-up but we opted based on this small set-up our goal for prior is the that our model is useful in domestic purpose and small set-up is quite sufficient. We want to further scale up this design for industrial use.

From our readings and calculations this model is useful indeed for domestic purposes as people can place this model each on their respective houses and use it.

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