CH.4

RESULTS & CONCLUSION

4.1 Introduction

In our project we are going to study the effect of method thermal heat storage of the solar water heating system performance. So we don't study the effect of solar angles or other parameters that affect on the solar water heating system, but we measure it and take it into consideration.

In this chapter we are going to show the different Results that we have been reached and compare it together to find the better and the maximum efficient method of thermal heat storage system to give the best performance from our solar heating system.

We will show the measurement devices used in our system and the measurement techniques and how we used in our work.

We first use only water in the storage tank to get the reference efficiency and performance from our system.

After that we add the encapsulated PCM sphere inside the storage tank. These capsules would contain paraffin wax as a phase change material.

We now study the effect of number of capsules inside the storage tank.

We add aluminum powder to the encapsulated phase change material to improve and enhance its thermal conductivity with different concentrations. We compare the different concentrations and choose the more efficient concentration to be used in coming different experiments.

We now use the most efficient concentration of aluminum powder to be injected inside PCM capsules. Our experiment now is to study the effect of number of capsules inside storage tank.

These results would tell us the best and maximum efficient method of thermal heat storage system. If it would be the latent heat storage system we will know the more efficient concentration of aluminum powder to be injected with paraffin wax into the capsules. We will also know the suitable number of capsules and its effect on the performance of the system.

4.2 The Measurement Devices

4.2.1 Measurement of Solar Irradiance

4.2.1.1 Global Solar Irradiance – Pyranometers

The primary instrument used to measure global solar irradiance is the Pyranometer, which measures the sun's energy coming from all directions (2π steradian) in the hemisphere above the plane of the instrument. The measurement is of the sum of the direct and the diffuse solar irradiance and is called the global solar irradiance.

The most common Pyranometer design uses a thermopile (multiple thermocouples connected in series) attached to a thin blackened absorbing surface shielded from convective loss and insulated against conductive losses as shown in Figure .

Fig 4.1 the Pyranometer

When it is placed in the sun, the surface attains a temperature proportional to the amount of radiant energy falling on it. The temperature is measured and converted through accurate calibration into readout of the global solar irradiance falling on the absorbing surface. A properly designed instrument measures radiation in all the solar wavelengths, and its response to direct radiation should be proportional to the cosine of the angle between the sun and a line normal to the Pyranometer absorber surface.

The typical use of a Pyranometer is for measurement of the global horizontal solar irradiance. For this purpose, it is placed in a horizontal orientation and sufficiently high above the surroundings so that it has a clear, hemispheric view of the entire sky with no shading or reflecting trees or buildings within this field of view.

For a horizontally oriented Pyranometer, the direct normal solar irradiance is reduced by the cosine of the angle of incidence, which in this case is the solar zenith angle θ_z.

The measured global horizontal solar irradiance is

$$I(solar\ irradiance) = (measured\ solar\ irradiance(in\ milli\ volts) \times 13.6) + 9.76$$

Pyranometers may also be used to, measure the global solar irradiance on inclined surfaces. An example would be measurements from a Pyranometer placed in the same plane as a tilted solar collector. As can be seen from the sketch in Figure

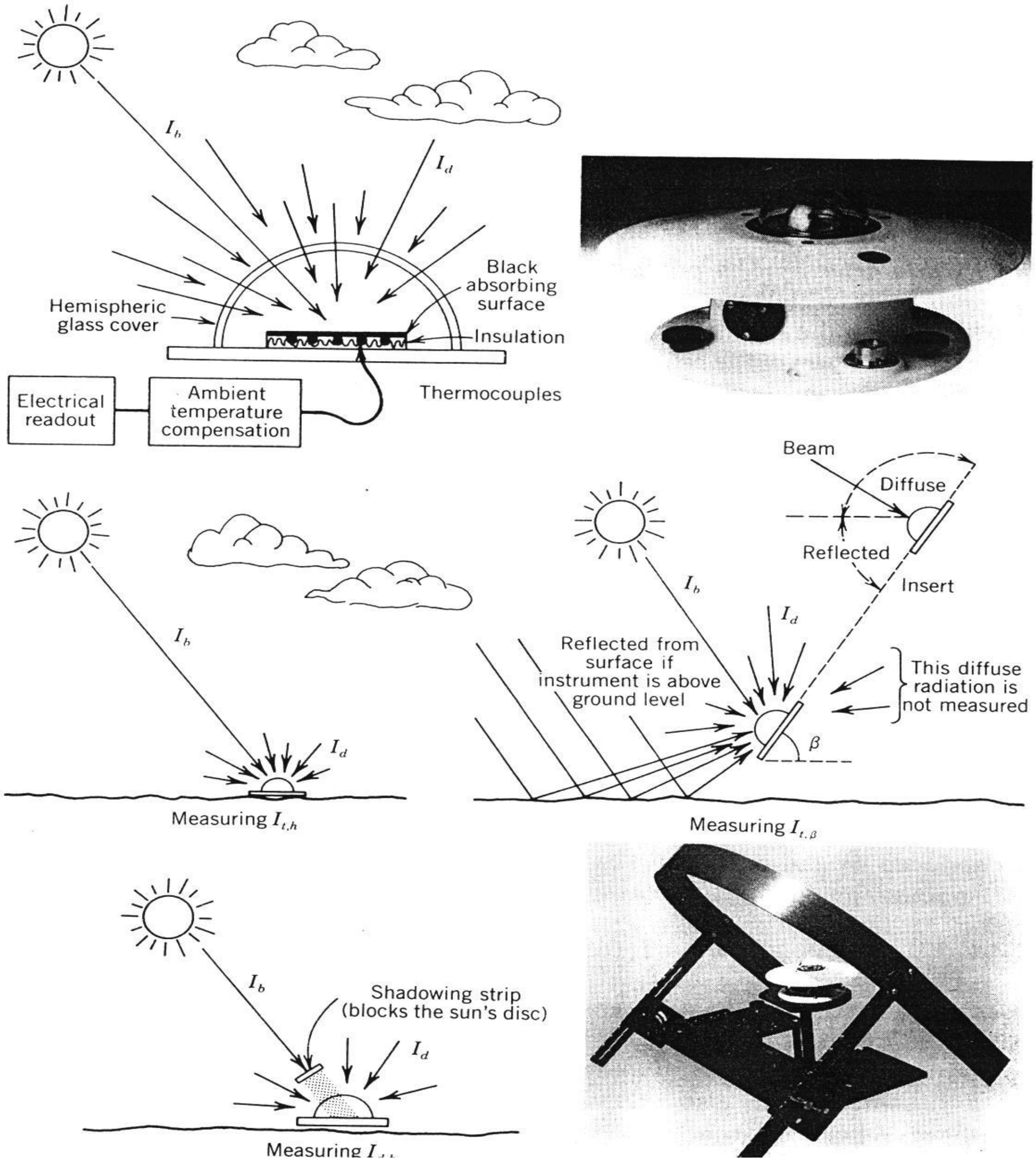


Fig 4.2 the Pyranometer position against incident radiation

This measurement now includes solar energy reflected from surrounding surfaces. However, various studies have indicated the possibility that the Pyranometer calibration may change with inclination.

Instead of using a blackened absorbing surface with thermocouples attached (a thermopile), investigators have proposed the use of silicon photovoltaic cells as an inexpensive alternative to the thermopile. The short-circuit current produced by these cells is proportional to the intensity of radiation striking the surface. Also, the rate of response of this current to changes in solar intensity is rapid.

There are two effects that limit the accuracy of photovoltaic cell Pyranometers and make them unsuitable as primary standards. These are:

(1) The cosine response of the surface of a bare silicon photovoltaic cell is inaccurate, and
(2) The spectral response of a solar cell is such that it is sensitive to the red and near-IR component of radiation and is insensitive to blue and violet light and the IR radiation of wavelengths longer than about 1.2 micrometers.

4.2.2 Thermocouples

4.2.2.1Background

A thermocouple is a junction between two different metals that produces a voltage related to a temperature difference. Thermocouples are a widely used type of temperature sensor for measurement and control and can also be used to convert heat into electric power. They are inexpensive and interchangeable, are supplied fitted with standard connectors, and can measure a wide range of temperatures. The main limitation is accuracy: system errors of less than one Kelvin (K) can be difficult to achieve.

Thermocouples are the most popular temperature sensors. They are cheap, interchangeable, have standard connectors and can measure a wide range of temperatures. The main limitation is accuracy, system errors of less than 1°C can be difficult to achieve.

4.2.2.2 How They Work

In 1822, an Estonian physician named Thomas See beck discovered (accidentally) that the junction between two metals generates a voltage which is a function of temperature. Thermocouples rely on this See beck effect. Although almost any two types of metal can be used to make a thermocouple, a number of standard types are used because they possess predictable output voltages and large temperature gradients.

Table containing Range of Temperatures for Each Thermocouple Type

Thermocouple Type	Overall Range (°C)	0.1°C Resolution	0.025°C Resolution
B	100..1800	1030..1800	-
E	-270..790	-240..790	-140..790
J	-210..1050	-210..1050	-120..1050
K	-270..1370	-220..1370	-20..1150
N	-260..1300	-210..1300	340..1260
R	-50..1760	330..1760	-
S	-50..1760	250..1760	-
T	-270..400	-230..400	-20..400

Type K (Chromel / Alumel) Type K is the 'general purpose' thermocouple. It is low cost and, owing to its popularity, it is available in a wide variety of probes. Thermocouples are available in the -200°C to +1200°C range. Sensitivity is approx 41uV/°C. Use type K unless you have a good reason not to.

Type E (Chromel / Constantan) Type E has a high output (68uV/°C) which makes it well suited to low temperature (cryogenic) use. Another property is that it is non-magnetic.

Type J (Iron / Constantan) Limited range (-40 to +750°C) makes type J less popular than type K. The main application is with old equipment that cannot accept 'modern' thermocouples. J types should not be used above 760°C as an abrupt magnetic transformation will cause permanent decalibration.

Type N (Nicrosil / Nisil) High stability and resistance to high temperature oxidation makes type N suitable for high temperature measurements without the cost of platinum (B,R,S) types. Designed to be an 'improved' type K, it is becoming more popular.

Thermocouple types B, R and S are all 'noble' metal thermocouples and exhibit similar characteristics. They are the most stable of all

thermocouples, but due to their low sensitivity (approx 10uV/0C) they are usually only used for high temperature measurement (>300°C).

Type B (Platinum / Rhodium) Suited for high temperature measurements up to 1800°C. Unusually type B thermocouples (due to the shape of their temperature / voltage curve) give the same output at 0°C and 42°C. This makes them useless below 50°C.

Type R (Platinum / Rhodium) Suited for high temperature measurements up to 1600°C. Low sensitivity (10uV/°C) and high cost makes them unsuitable for general purpose use.

Type S (Platinum / Rhodium) Suited for high temperature measurements up to 1600°C. Low sensitivity (10uV/vC) and high cost makes them unsuitable for general purpose use. Due to its high stability type S is used as the standard of calibration for the melting point of gold (1064.43°C).

Thermocouple Selection

Thermocouples are available either as bare wire 'bead' thermocouples which offer low cost and fast response times, or built into probes. A wide variety of probes are available, suitable for different measuring applications (industrial, scientific, food temperature, medical research etc). One word of warning: when selecting probes take care to ensure they have the correct type of connector. The two common types of connector are 'standard' with round pins and 'miniature' with flat pins; this causes some confusion as 'miniature' connectors are more popular than 'standard' types.

A K type thermocouple is the most popular and uses nickel-chromium and nickel-aluminum alloys to generate voltage. Standard tables show the voltage produced by thermocouples at any given temperature, so the K type thermocouple at 300°C will produce 12.2mV. Unfortunately it is not possible to simply connect up a voltmeter to the thermocouple to measure this voltage, because the connection of the voltmeter leads will make a second, undesired thermocouple junction.

<u>Fig 4.3</u> **the K type thermocouple**

<u>Fig 4.4</u> **the voltmeter used to measure the temperature using thermocouple**

4.2.2.3 Voltage–temperature relationship

The nonlinear relationship between the temperature difference (ΔT) and the output voltage (mV) of a thermocouple can be approximated by a polynomial:

$$\Delta T = \sum_{n=0}^{N} a_n v^n$$

The coefficients are given for n from 0 to between 5 and 13 depending upon the metals. In some cases better accuracy is obtained with additional non-polynomial terms.

Cold Junction Compensation (CJC)

To make accurate measurements, this must be compensated for by using a technique known as cold junction compensation (CJC). In case you are wondering why connecting a voltmeter to a thermocouple does not make several additional thermocouple junctions (leads connecting to the thermocouple, leads to the meter, inside the meter etc), the law of intermediate metals states that a third metal, inserted between the two dissimilar metals of a thermocouple junction will have no effect provided that the two junctions are at the same temperature. This law is also important in the construction of thermocouple junctions. It is acceptable to make a thermocouple junction by soldering the two metals together as the solder will not affect the reading. In practice, thermocouple junctions are made by welding the two metals together (usually by capacitive discharge). This ensures that the performance is not limited by the melting point of solder.

All standard thermocouple tables allow for this second thermocouple junction by assuming that it is kept at exactly zero degrees centigrade. Traditionally this was done with a carefully constructed ice bath (hence the term 'cold' junction compensation). Maintaining a ice bath is not practical for most measurement applications, so instead the actual temperature at the point of connection of the thermocouple wires to the measuring instrument is recorded.

Typically cold junction temperature is sensed by a precision thermostat in good thermal contact with the input connectors of the measuring instrument. This second temperature reading, along with the reading from the thermocouple itself is used by the measuring instrument to calculate the true temperature at the thermocouple tip.

For less critical applications, the CJC is performed by a semiconductor temperature sensor. By combining the signal from this semiconductor with the signal from the thermocouple, the correct reading can be obtained without the need or expense to record two temperatures. Understanding of cold junction compensation is important; any error in the measurement of cold junction temperature will lead to the same error in the measured temperature from the thermocouple tip.

Linearization

As well as dealing with CJC, the measuring instrument must also allow for the fact that the thermocouple output is non linear. The relationship between temperature and output voltage is a complex polynomial equation (5^{th} to 9^{th} order depending on thermocouple type). Analogue methods of linearization are used in low cost thermocouple meters. High accuracy instruments store thermocouple tables in computer memory to eliminate this source of error.

Precautions and Considerations for Using Thermocouples

Most measurement problems and errors with thermocouples are due to a lack of understanding of how thermocouples work. Thermocouples can suffer from ageing and accuracy may vary consequently especially after prolonged exposure to temperatures at the extremities of their useful operating range. Listed below are some of the more common problems and pitfalls to be aware of.

Many measurement errors are caused by unintentional thermocouple junctions. Remember that any junction of two different metals will cause a junction. If you need to increase the length of the leads from your thermocouple, you must use the correct type of thermocouple extension wire (eg type K for type K thermocouples). Using any other type of wire will introduce a thermocouple junction. Any connectors used must be made of the correct thermocouple material and correct polarity must be observed.

4.3 The Measurement Techniques

Here we will mention the different measurement techniques we used to get our desired results from measuring the solar irradiance to the flow rate output from the tank and flow rate in the collector and ending with the temperatures in different places along the thermal solar heater.

4.3.1 For The solar irradiance

The measurement technique depends on measuring the solar irradiance using global solar irradiance measuring device which is the Pyranometer. The two wires out from the Pyranometer would be connected to the voltmeter.

We measured the solar irradiance every 15 minutes from 10:00 AM to 2:00 PM on the angle we set the collector on 30 degree.

4.3.2 For the Temperature

The temperature is measured using thermometers distributed on the collector and the tank as followed:

1. on the collector inlet

Fig 4.5thermocouple at collector inlet

2. on the collector outlet

Fig 4.6 thermocouple at the collector outlet

3. on the absorber

Fig 4.7 thermocouples on the absorber

4. inside the tank

<u>Fig 4.8</u> the thermometer used inside storage tank

5. PCM capsules surface and internal temperatures

*** On surface we use two thermocouples welded to the surface**

<u>Fig 4.9</u> thermocouples on outer surface of PCM capsules

4.4 The Measured Data

4.4.1 Day 1(5/62012) – Angle 30° for only water inside the tank:

TIME	T_{amb} (°C)	$T_{plate,pipe}$ (°C)	$T_{plate,fin}$ (°C)	S (mv)	S (W/m²)
١٠:٣٠ ص	29	64	64.5	52	716.9
١١:٠٠ ص	33.5	71	74	55	757.7
١١:٣٠ ص	36.6	74.6	78.5	60.5	832.5
١٢:٠٠ ص	37.8	75.5	79.1	61.3	843.38
١٢:٣٠ ص	38.2	77.5	80	61	839.3
٠١:٠٠ ص	39.2	80.3	83.5	59	812.1
٠١:٣٠ ص	39.2	82	84.3	54.9	756.34
٠٢:٠٠ ص	36.2	81.2	81.8	43.9	606.74

$$\eta = FR\,(\tau\,\alpha) - FR\,UL\,([Ti - Tamb]/S)$$

$$\tau\,\alpha = 0.89$$

$$U_L = U_B + U_S + U_T$$

$$U_B = \frac{K}{\text{bottom thickness}}$$

$$U_S = \frac{\frac{K}{\text{side thickness}} \times \text{prameter of collector} \times \text{thickness of collector}}{\text{area of collector}}$$

$$U_T = \left[\frac{N}{\frac{C}{T_{P,m}} \times \left[\frac{T_{P,m} - T_a}{N + f}\right]^e} + \frac{1}{h_w}\right]^{-1} + \left[\frac{\sigma\,(T_{P,m} + T_a)\,(T_{P,m}^2 + T_a^2)}{(\varepsilon_P + .00591 \times N.h_w)^{-1} + \frac{2N + f - 1 + 0.133\,\varepsilon_P}{\varepsilon_g} - N}\right]$$

Where : $C = 520 \times (1 - 0.000051 \times \beta^2)$ & $e = 0.43\left(1 - \frac{100}{T_{P,m}}\right)$

And $f = (1 - 0.089\,h_w - 0.1126\,h_w\,\varepsilon_P)\,(1 + 0.07866\,N)$

$$F = \frac{\tanh\left(m \times \frac{W - D}{2} \right)}{m \times \frac{W - D}{2}} \qquad \& \qquad m = \sqrt{\frac{U_L}{K\,\delta}}$$

Where K_{fin} = 385 W/m.K & δ_{fin} = 0.35 mm.

and W-D = 11 cm & D_{riser} = 11 mm. & D_i = 10 mm.

K_{bond} = 109 W/m.K with b = 0.01366 m and ϒ = 0.0015 m

We let $h_{fg,water}$ = 600 W/m.K

$$F^{\backslash} = \frac{\frac{1}{U_L}}{W \left[\frac{1}{U_L\,(D + [W - D]\,F)} + \frac{1}{C_\beta} + \frac{1}{\pi\,D_i\,h_{f,i}} \right]}$$

$$F_R = \frac{m^{\cdot}\,C_P}{A_C\,U_L} \left[1 - e^{\left(- F^{\backslash} \frac{AC\,UL}{m^{\cdot}\,CP} \right)} \right] \qquad \& \qquad m^{\cdot} = Q \times \rho$$

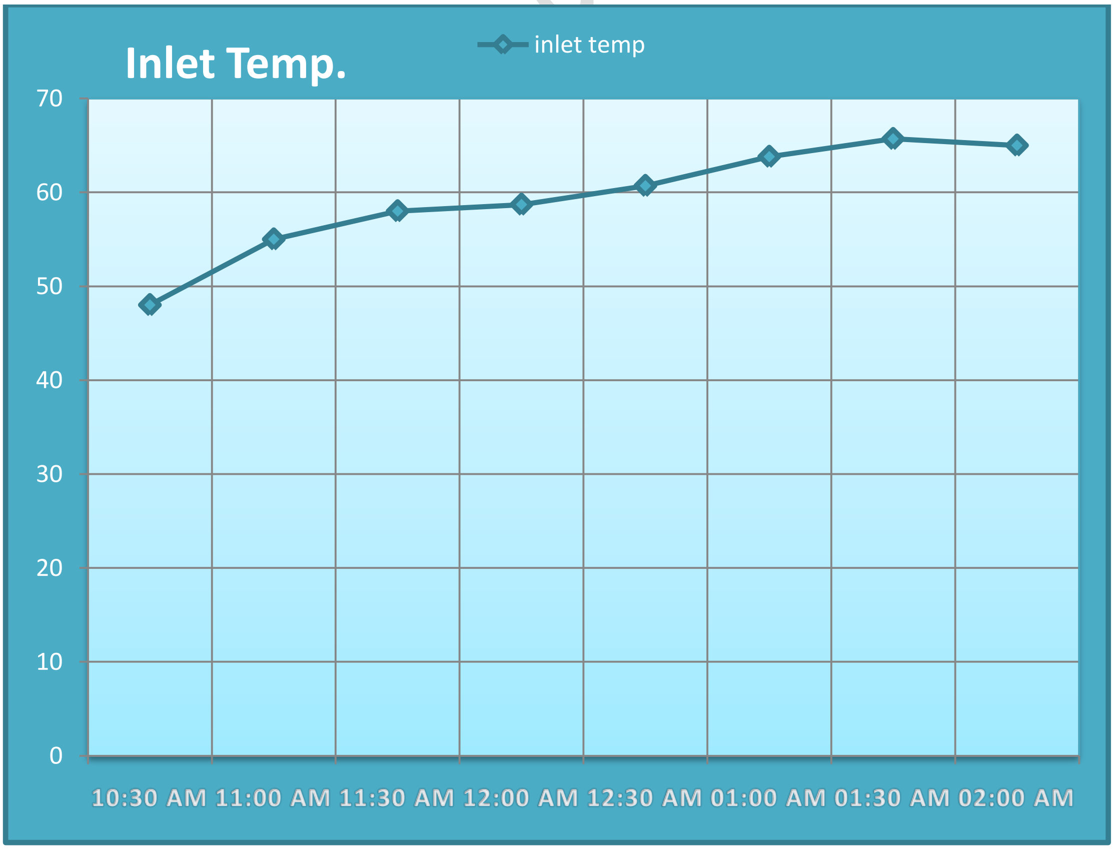
UL calculation						
β	=	30	degree	→	C =	519.0459
ε_g	=	0.89				
ε_p	=	0.93				
N	=	1				
h_w	=	5	W/m.°C	→	f =	0.033880711
$H_{collector.}$	=	80	mm. =		0.08	m.
$L_{collector.}$	=	1	m.			
$W_{collector.}$	=	1	m.			
$K_{ins.}$	=	0.036	W/m.K.			
$H_{back\ ins.}$	=	40	mm. =		0.04	m.
$H_{edge\ ins.}$	=	25	mm. =		0.025	m.
σ	=	5.67E-08	W/m2.K4.			

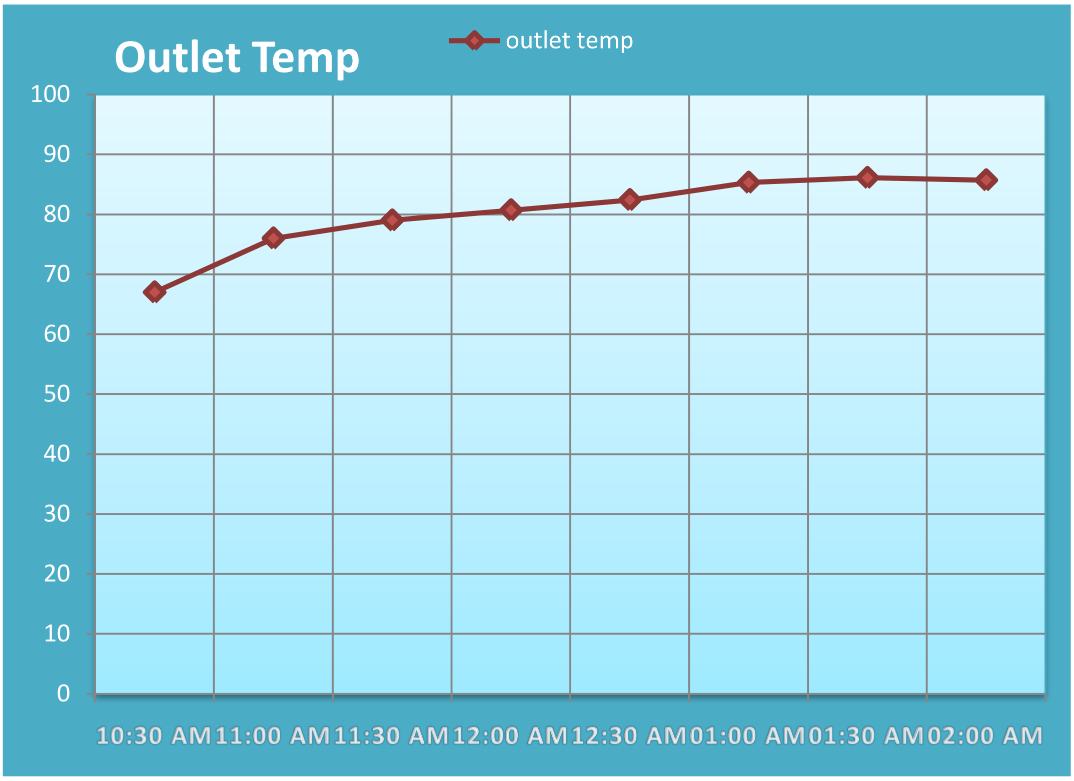
TIME	T_{amb} (K)	$T_{plate,fin}$ (K)	e	U_T (W/m2.K)	U_B (W/m^2.K)	Us (W/m^2.K)	U_L (W/m^2.K)
١٠:٣٠ ص	302	337.5	0.302592593	7.876780653	0.9	0.4608	9.237580653
١١:٠٠ ص	306.5	347	0.306080692	8.282343756	0.9	0.4608	9.643143756
١١:٣٠ ص	309.6	351.5	0.307667141	8.495446354	0.9	0.4608	9.856246354
١٢:٠٠ ص	310.8	352.1	0.307875604	8.537842338	0.9	0.4608	9.898642338
١٢:٣٠ ص	311.2	353	0.308186969	8.577429149	0.9	0.4608	9.938229149
٠١:٠٠ ص	312.2	356.5	0.309382889	8.722263577	0.9	0.4608	10.08306358
٠١:٣٠ ص	312.2	357.3	0.309652953	8.751269961	0.9	0.4608	10.11206996
٠٢:٠٠ ص	309.2	354.8	0.308804961	8.606543341	0.9	0.4608	9.967343341

TIME	U_L (W/m2.K)	m	m*(W-D)/2	F	F`	(m`*Cp)/(Ac*UL)	FR
١٠:٣٠ ص	9.2375806	8.2797025	0.4553836	0.936165	0.8912170	7.5416572	0.835226
١١:٠٠ ص	9.6431437	8.4595046	0.4652727	0.933585	0.8891138	7.2244766	0.831272
١١:٣٠ ص	9.8562463	8.5524666	0.4703856	0.932236	0.8880127	7.0682757	0.829207
١٢:٠٠ ص	9.8986423	8.5708408	0.4713962	0.931969	0.887794	7.0380022	0.828798
١٢:٣٠ ص	9.9382291	8.5879620	0.4723379	0.931719	0.8875898	7.0099678	0.828416
٠١:٠٠ ص	10.083063	8.6503138	0.4757672	0.930806	0.8868437	6.9092757	0.827021
٠١:٣٠ ص	10.112069	8.6627473	0.4764511	0.930624	0.8866944	6.889456	0.826742
٠٢:٠٠ ص	9.9673433	8.6005321	0.4730292	0.931535	0.8874397	6.989492	0.828135

TIME	U_L (W/m2.K)	FR	T_{amb} (°C)	T_i (°C)	S (W/m2)	[Ti - Tamb] /S	η
١٠:٣٠ ص	9.23758	0.835226	29	48	716.9	0.0265029	0.5388686
١١:٠٠ ص	9.643143	0.831272	33.5	55	757.7	0.0283753	0.5123732
١١:٣٠ ص	9.856246	0.829207	36.6	58	832.5	0.0257057	0.5279054
١٢:٠٠ ص	9.898642	0.828798	37.8	58.7	843.38	0.0247812	0.5343257
١٢:٣٠ ص	9.938229	0.828416	38.2	60.7	839.3	0.026808	0.5165799
٠١:٠٠ ص	10.08306	0.827021	39.2	63.8	812.1	0.0302918	0.4834479
٠١:٣٠ ص	10.11206	0.826742	39.2	65.7	756.34	0.035037	0.4428873
٠٢:٠٠ ص	9.967343	0.828135	36.2	65	606.74	0.0474667	0.3452349

Curves shows day 1 results




Outlet Temp
outlet temp
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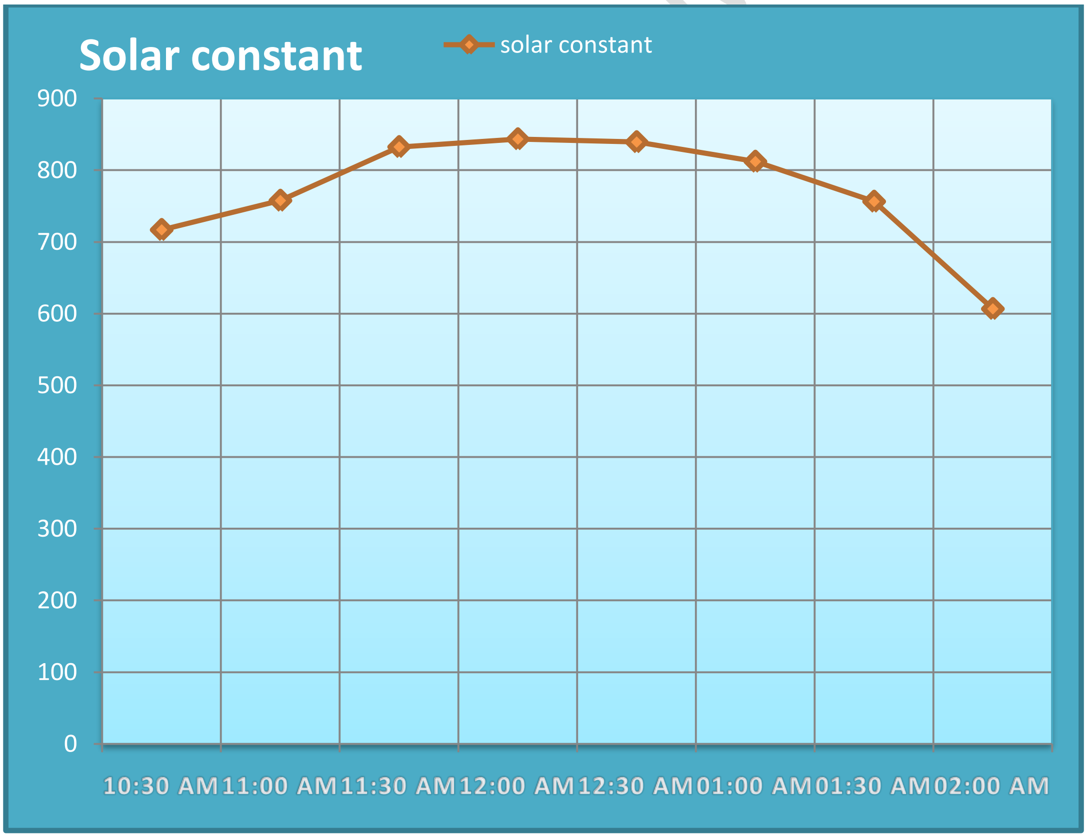
Solar constant
solar constant
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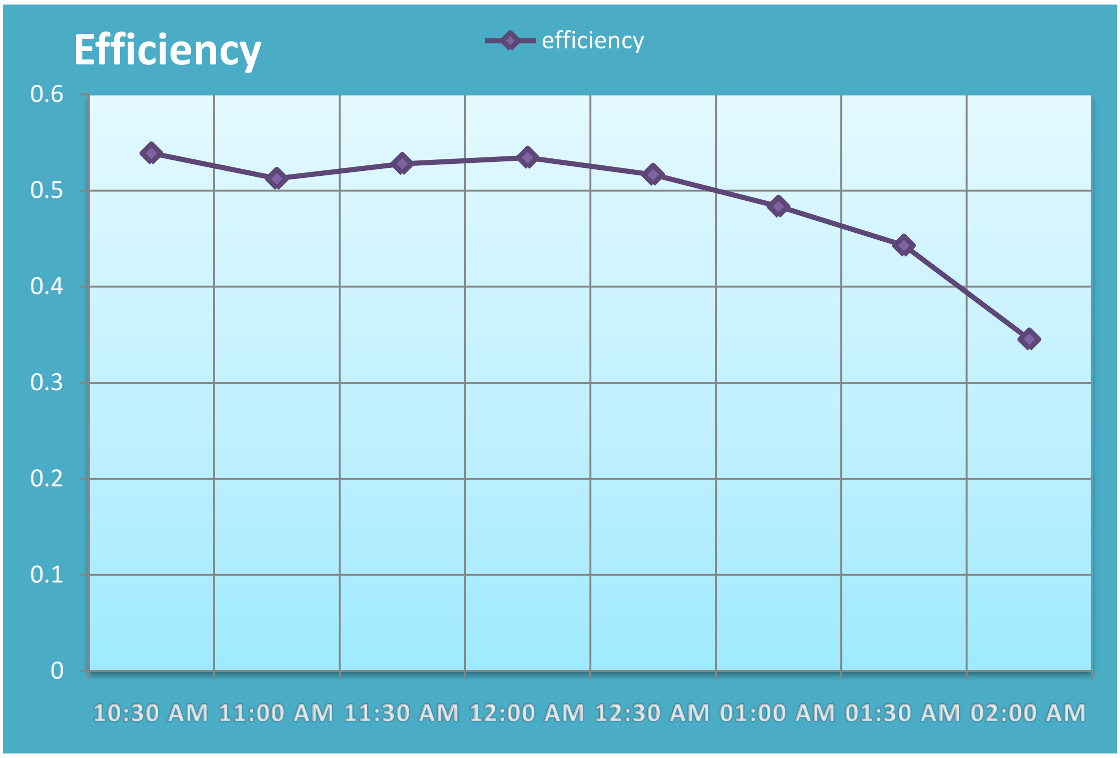
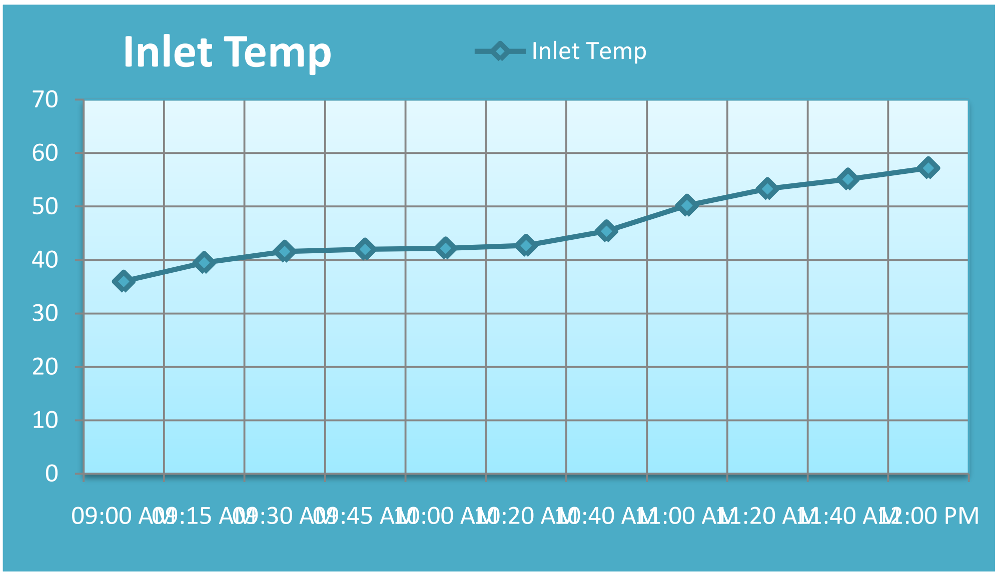
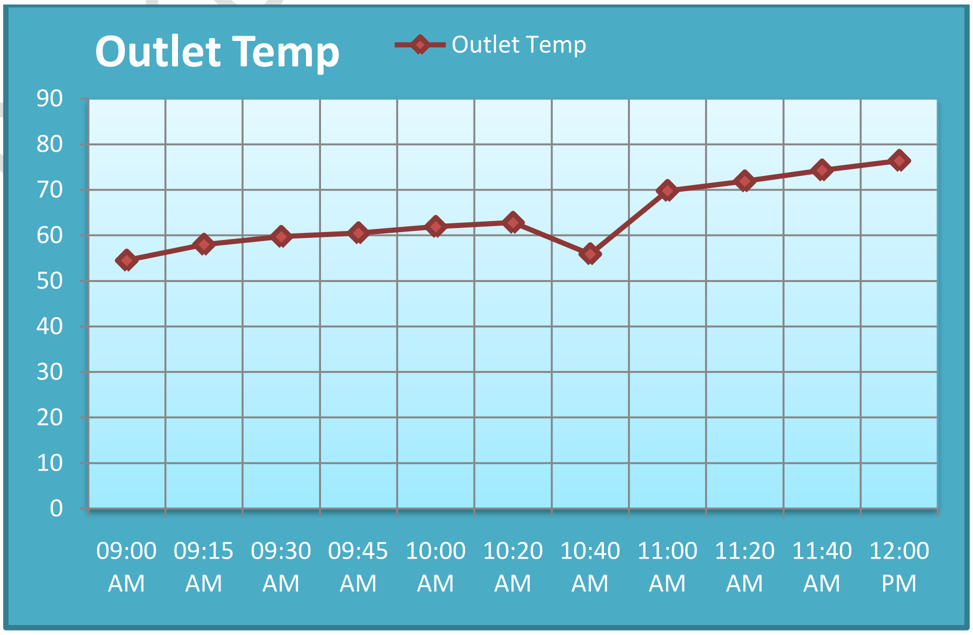


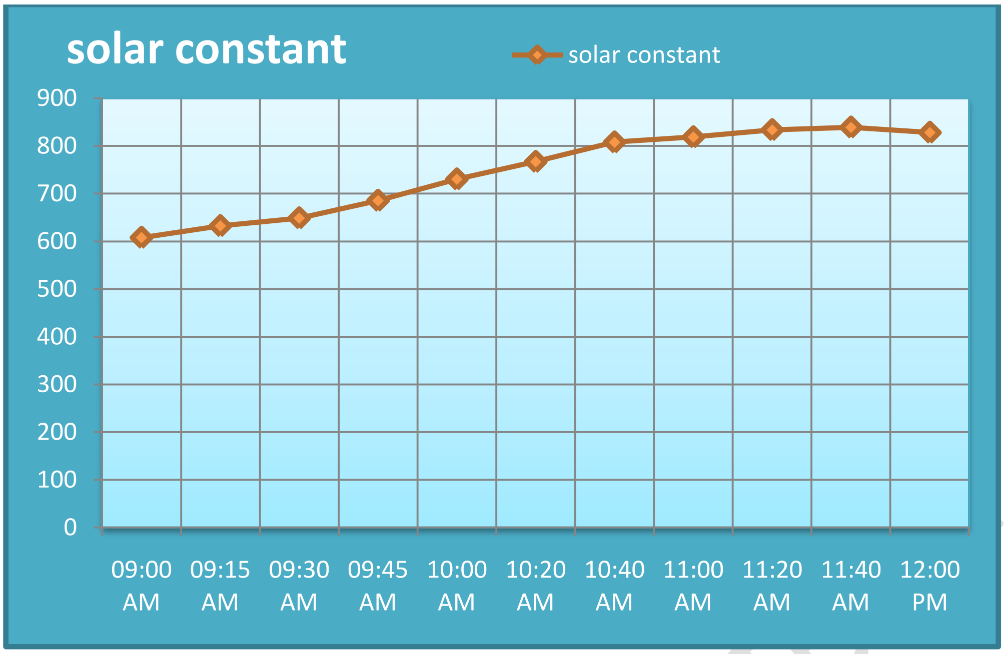
4.4.2 Day 2 (6/6/2012) – Angle 30° for water with PCM capsules of concentration 0.1gm and 0.4gm Aluminum powder inside tank:

Time(min)	T_{fin} c	T pipe	T tank
٠٩:٠٠ ص	54	51	41
٠٩:١٥ ص	57.5	55.6	42
٠٩:٣٠ ص	59	57.7	43.2
٠٩:٤٥ ص	60.3	58.2	46
١٠:٠٠ ص	62	58.9	58
١٠:٢٠ ص	63	61	58.5
١٠:٤٠ ص	66	63.6	59.5
١١:٠٠ ص	69.9	66.6	60
١١:٢٠ ص	72.7	69.1	62
١١:٤٠ ص	74.6	71.3	63
١٢:٠٠ م	67.5	73.3	64.5

Time(min)	T_i c	T_o c	S (mV)	S (W/m^2)
٠٩:٠٠ ص	36	54.5	44	608.1
٠٩:١٥ ص	39.5	58	45.8	632.58
٠٩:٣٠ ص	41.6	59.7	47	648.9
٠٩:٤٥ ص	42	60.5	49.7	685.62
١٠:٠٠ ص	42.2	61.9	53	730.5
١٠:٢٠ ص	42.7	62.8	55.7	767.22
١٠:٤٠ ص	45.4	55.9	58.7	808.02
١١:٠٠ ص	50.2	69.8	59.5	818.9
١١:٢٠ ص	53.3	71.9	60.6	833.86
١١:٤٠ ص	55.1	74.3	61	839.3
١٢:٠٠ م	57.2	76.4	60.2	828.42



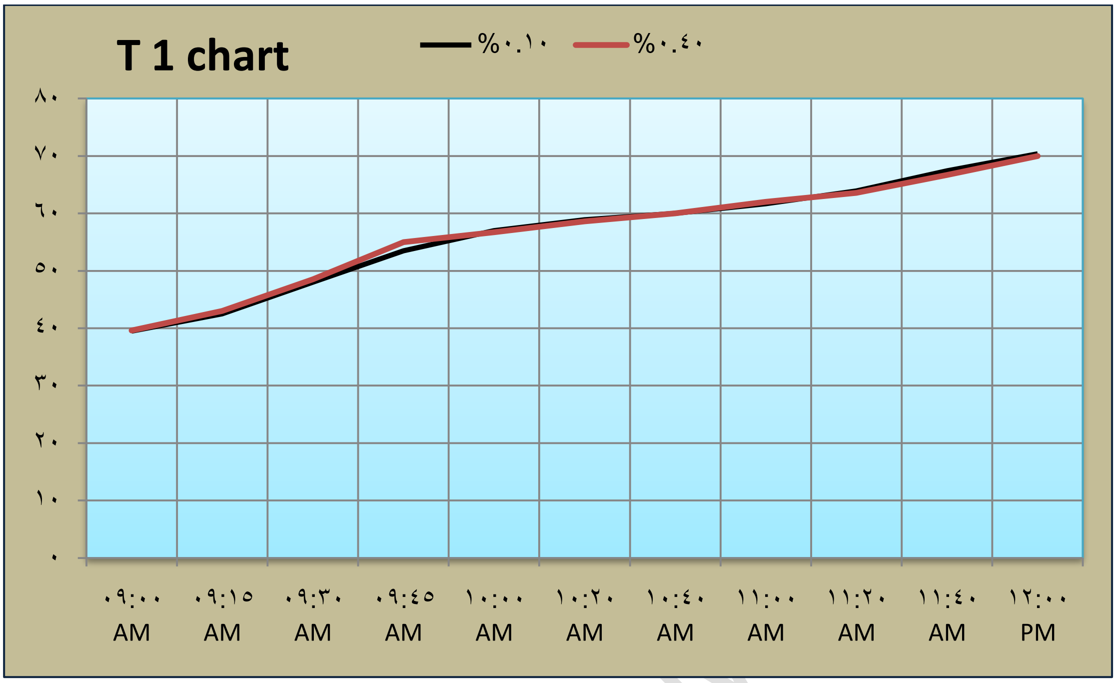


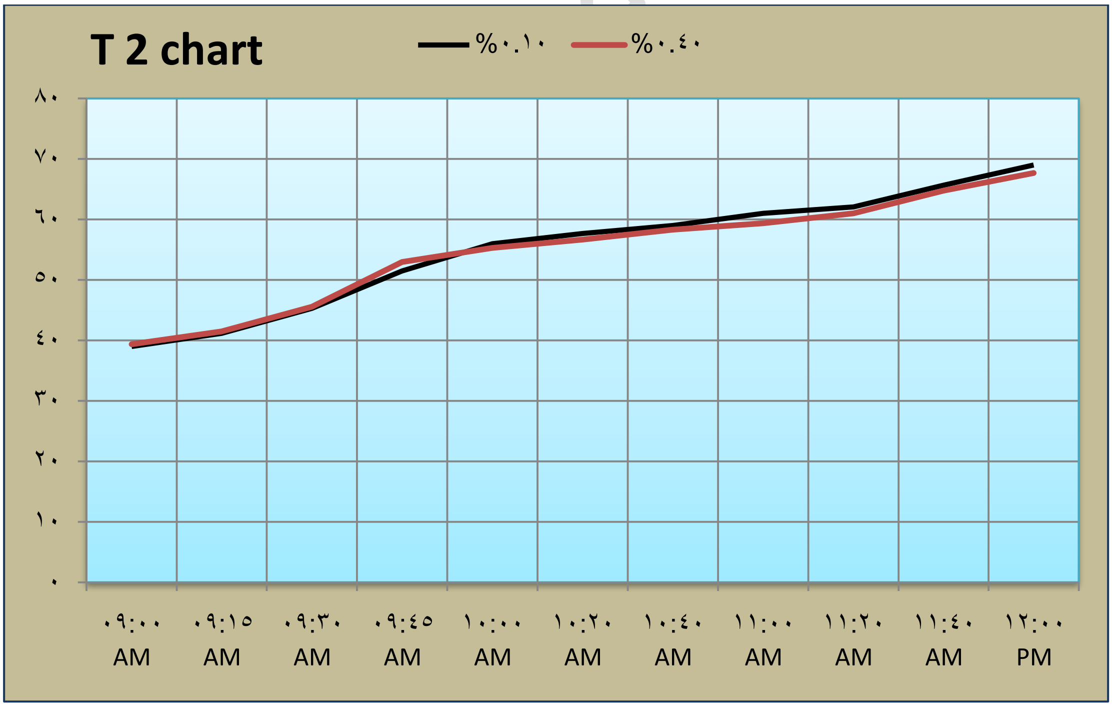


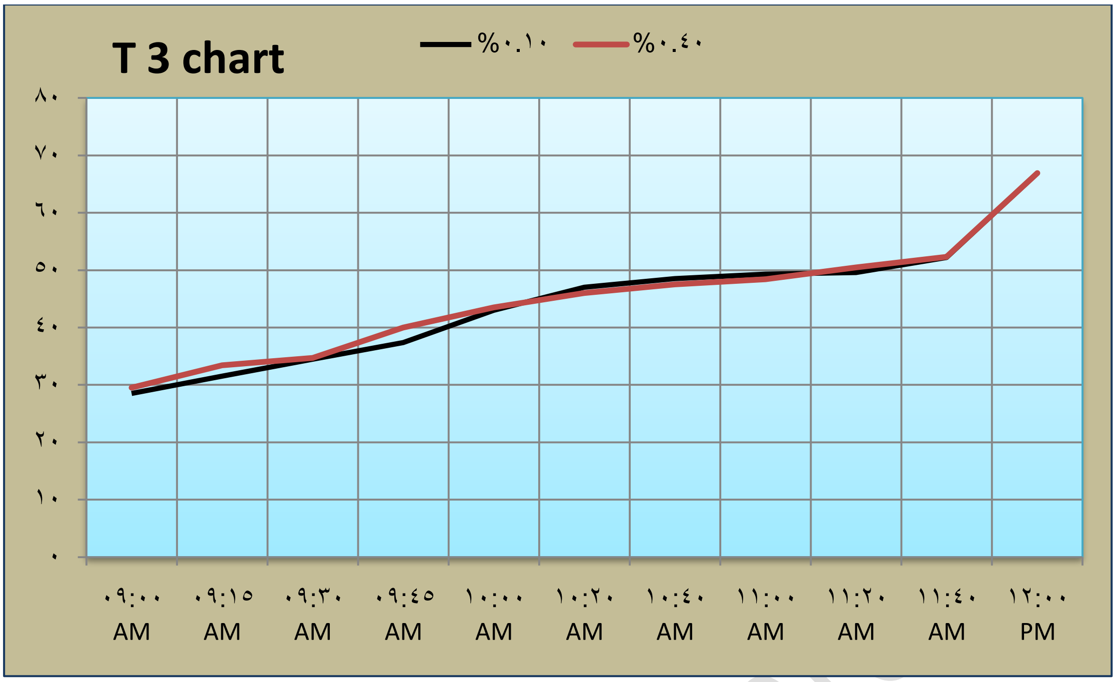
	For (0.1 gm) of alluminum powder						
Time(min)	T1	T2	T3	T4	T5	T6	Tavg
٠٩:٠٠ ص	39.5	39	28.5	29	35	36	34.5
٠٩:١٥ ص	42.5	41.2	31.5	32.5	39	40.2	37.81667
٠٩:٣٠ ص	48	45.3	34.5	35.2	41.3	42	41.05
٠٩:٤٥ ص	53.5	51.5	37.4	39.6	46.7	48.2	46.15
١٠:٠٠ ص	57	56	43	44.1	50.5	51.3	50.31667
١٠:٢٠ ص	58.9	57.7	47	47.2	53.7	54	53.08333
١٠:٤٠ ص	60	59	48.5	49	55.9	56.3	54.78333
١١:٠٠ ص	61.7	61	49.3	50	58.1	58.4	56.41667
١١:٢٠ ص	63.9	62.1	49.6	50.5	58.4	59.6	57.35
١١:٤٠ ص	67.4	65.7	52.2	52	61.5	62	60.13333
١٢:٠٠ م	70.4	69	66.9	65.8	65.4	65.7	67.2

	For (0.4 gm) of alluminum powder						
Time(min)	T1	T2	T3	T4	T5	T6	Tavg
٠٩:٠٠ ص	39.6	39.4	29.5	33	37.5	38	36.1667
٠٩:١٥ ص	43	41.5	33.4	34.6	40.5	40.6	38.93333
٠٩:٣٠ ص	48.5	45.6	34.7	36.8	42.2	42.6	41.73333
٠٩:٤٥ ص	55	53	40	42.5	49.2	49.3	48.16667
١٠:٠٠ ص	56.7	55.3	43.5	46	52	52.1	50.93333
١٠:٢٠ ص	58.6	56.7	46	47.7	54.2	55	53.03333
١٠:٤٠ ص	60	58.3	47.5	49.2	56.2	56.9	54.68333
١١:٠٠ ص	62	59.4	48.4	50.5	58.1	58.7	56.18333
١١:٢٠ ص	63.6	61	50.5	52.6	59.5	60	57.86667
١١:٤٠ ص	66.7	64.8	52.3	54.5	61.8	62.4	60.41667
١٢:٠٠ م	70	67.7	66.9	65.5	66	65.5	66.93333

When we compare the temperature distribution on surface and inside the two capsules at the same moment we get this curves:






T 3 chart
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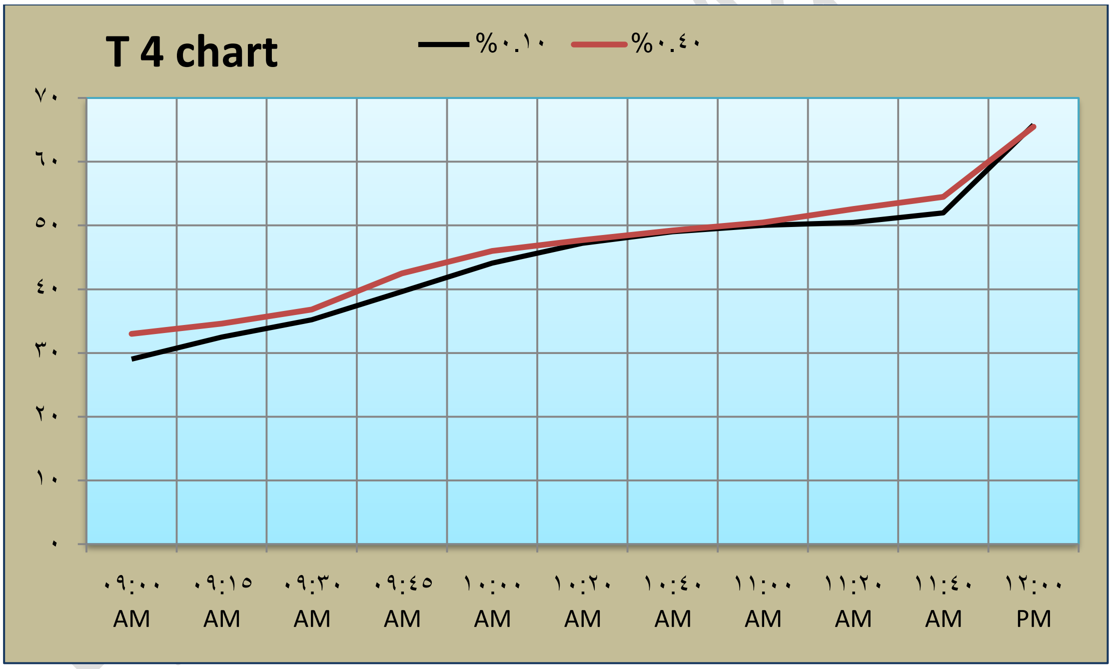
T 4 chart
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٠٩:٤٥ AM
١٠:٠٠ AM
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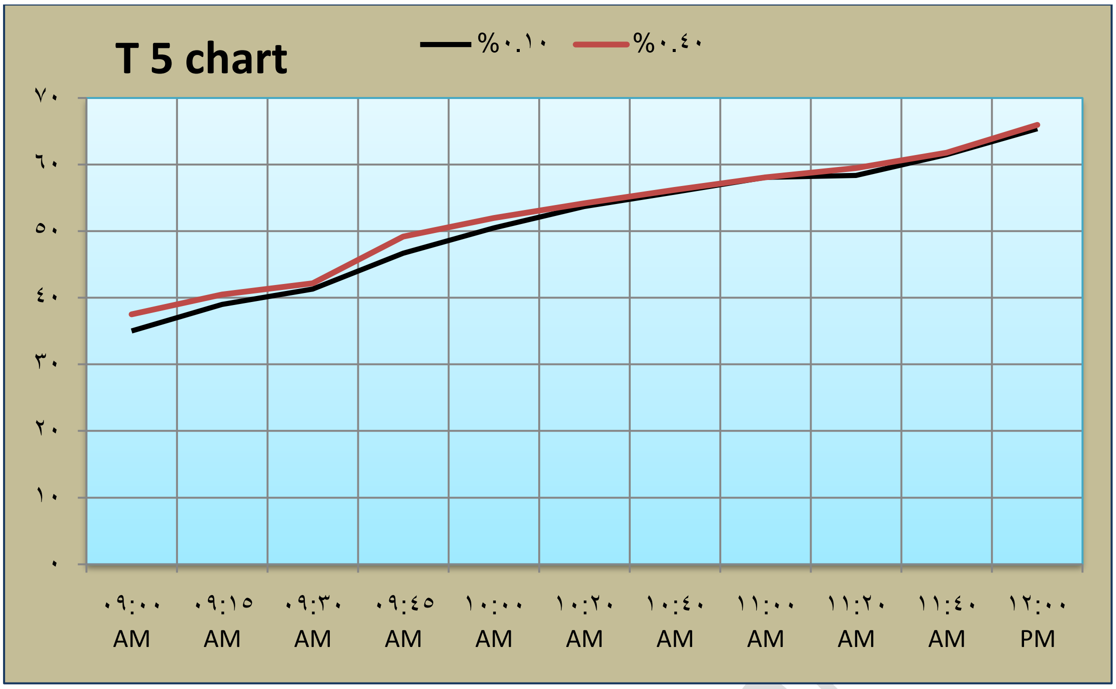
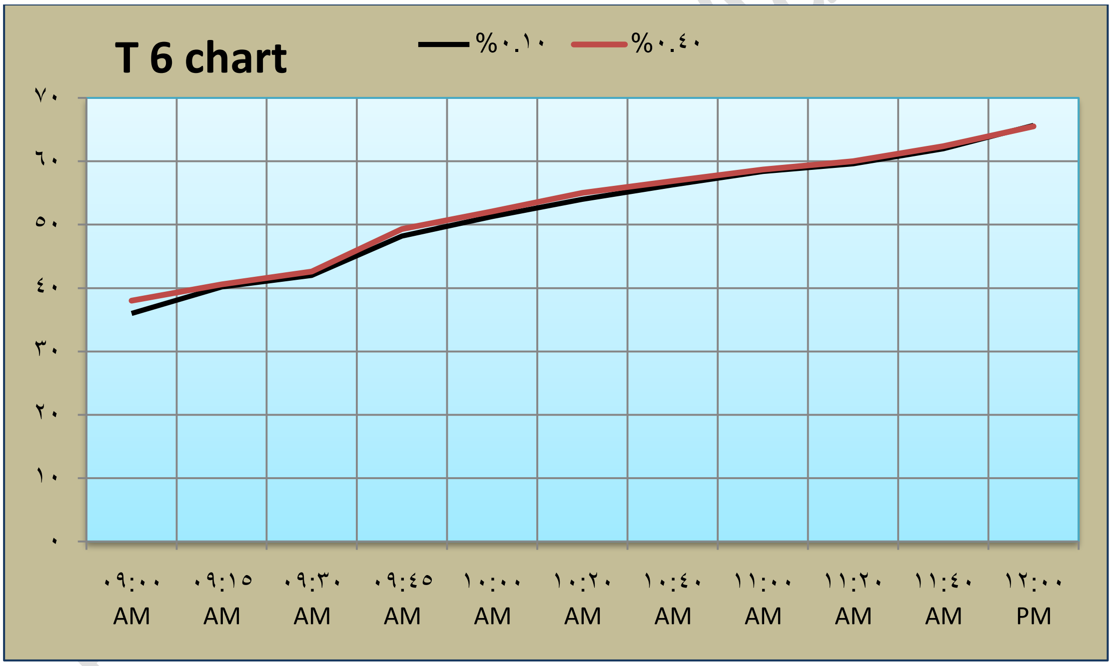
١٢:٠٠ PM





It is clear that 0.4 concentration capsule reaches higher temperatures than the other one, especially after melting point.

Now there are two parts of thermal energy stored inside the storage tank:

1. **Heat stored due to rise in water temperature**

$$Q_w = \dot{m}_w * C_{p,water} * (T_{tank} - T_s)$$

Assume that $\dot{m}_w = \dot{v}_w * \rho_w = (\frac{1*0.001}{60}) * 1000 = 0.016667$ **kg/s**

And we have $T_s = 32\ ^oC$ **&** $C_{p,water} = 4180$ **J/kg.K**

Time(min)	T tank	Qw
٠٩:٠٠ ص	41	104.5
٠٩:١٥ ص	42	116.1111
٠٩:٣٠ ص	43.2	130.0444
٠٩:٤٥ ص	46	162.5556
١٠:٠٠ ص	58	301.8889
١٠:٢٠ ص	58.5	307.6944
١٠:٤٠ ص	59.5	319.3056
١١:٠٠ ص	60	325.1111
١١:٢٠ ص	62	348.3333
١١:٤٠ ص	63	359.9444
١٢:٠٠ م	64.5	377.3611

2. **Heat stored inside two capsules and can be calculated from the relation**

$$Q = \dot{m}_{pcm}\left[\left\{\int_{T_1}^{T_*} C_{P,S}.\,dT\right\}_{pcm} + h_{fg,pcm} + \left\{\int_{T_*}^{T_2} C_{p,l}.\,dT\right\}_{pcm}\right]$$

The amount of PCM inside two capsules

$$m_{pcm} = \rho_{pcm} * v_{capsule} = 780 * \left(\frac{4}{3} * \pi * .04^3\right) = 0.2091\ kg$$

$\dot{m}_{pcm} = m_{pcm}$ / time =0.2091/(3*3600) = 1.93615*10^{-5} kg/s

$h_{fg,pcm}$ = 266000 J/kg & T^* = 54 °C

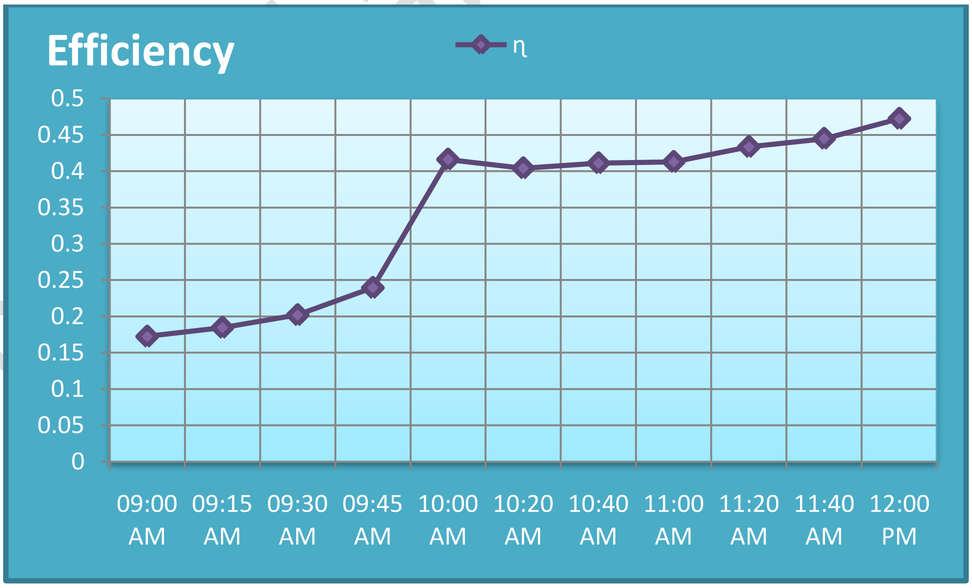
$C_{P,S}$ = 2900 J/kg.K & $C_{p,l}$ = 2130 J/kg.K

Time(min)	T tank	Tavg (0.1)	Qcapsule 0.1	Tavg (0.4)	Qcapsule 0.4
٠٩:٠٠ ص	41	34.5	0.14037088	36.1667	0.23395333
٠٩:١٥ ص	42	37.81667	0.32659642	38.93333	0.38929504
٠٩:٣٠ ص	43.2	41.05	0.50814257	41.73333	0.54651042
٠٩:٤٥ ص	46	46.15	0.79449915	48.16667	0.907731845
١٠:٠٠ ص	58	50.31667	1.0284508	50.93333	1.06307524
١٠:٢٠ ص	58.5	53.08333	1.18379419	53.03333	1.180986775
١٠:٤٠ ص	59.5	54.78333	6.41360323	54.68333	6.413603226
١١:٠٠ ص	60	56.41667	6.47546322	56.18333	6.475463218

١١:٢٠ ص	62	57.35	6.54488415	57.86667	6.544884151
١١:٤٠ ص	63	60.13333	6.65004614	60.41667	6.650046139
١٢:٠٠ م	64.5	67.2	6.91879316	66.93333	6.918793165

The total useful energy is the sum of these values. The efficiency can be calculated after that.

Time(min)	Qw	Qcapsule 0.1	Qcapsule 0.4	Qu	S (W/m^2)	η
٠٩:٠٠ ص	104.5	0.14037088	0.23395333	104.8743	608.1	0.172462
٠٩:١٥ ص	116.1111	0.32659642	0.38929504	116.827	632.58	0.184683
٠٩:٣٠ ص	130.0444	0.50814257	0.54651042	131.0991	648.9	0.202033
٠٩:٤٥ ص	162.5556	0.79449915	0.907731845	164.2578	685.62	0.239576
١٠:٠٠ ص	301.8889	1.0284508	1.06307524	303.9804	730.5	0.416127
١٠:٢٠ ص	307.6944	1.18379419	1.180986775	310.0592	767.22	0.404133
١٠:٤٠ ص	319.3056	6.41360323	6.413603226	332.1328	808.02	0.411045
١١:٠٠ ص	325.1111	6.47546322	6.475463218	338.062	818.9	0.412825
١١:٢٠ ص	348.3333	6.54488415	6.544884151	361.4231	833.86	0.433434
١١:٤٠ ص	359.9444	6.65004614	6.650046139	373.2445	839.3	0.444709
١٢:٠٠ م	377.3611	6.91879316	6.918793165	391.1987	828.42	0.472223

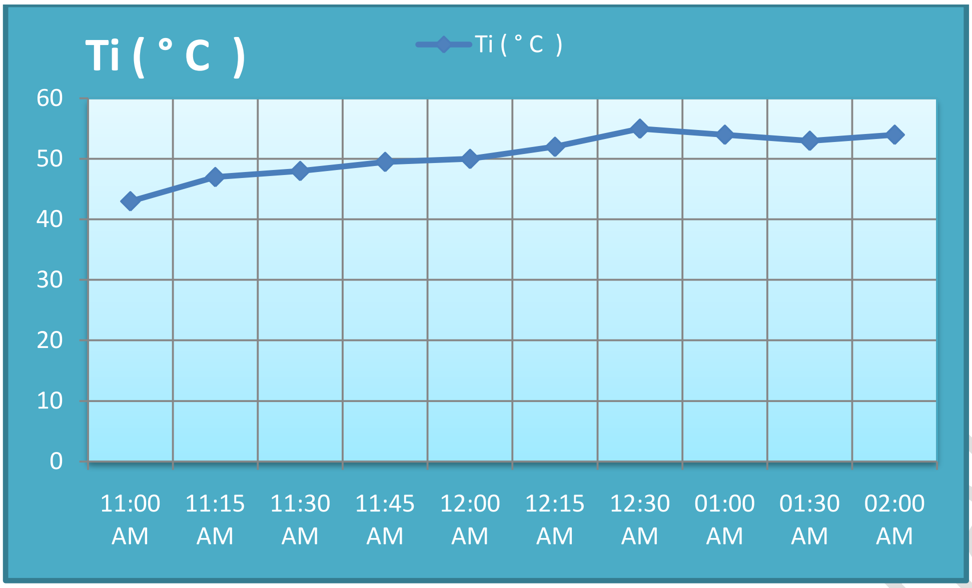


4.4.5 Day 3(10/62012) – Angle 30° for water with 4 PCM capsules of concentration 0.7gm Aluminum powder together inside tank:

Now we will use more aluminum concentration and use more than one capsule.

TIME	T_{amb} (° C)	$T_{plate,pipe}$ (° C)	$T_{plate,fin}$ (° C)	T_{tank} (° C)
١١:٠٠ ص	32.5	62	68	51
١١:١٥ ص	32.8	65	70	54
١١:٣٠ ص	32.8	68	71	56
١١:٤٥ ص	33	70	73	56.5
١٢:٠٠ ص	34.2	72	74	59
١٢:١٥ ص	35.7	73	74.5	63
١٢:٣٠ ص	36	73.7	75	64
٠١:٠٠ ص	36.5	67	67	65
٠١:٣٠ ص	37	71	72	67
٠٢:٠٠ ص	33	69	70	67

TIME	T_i (°c)	T_o (°c)	S (mv)	S (W/m2)
١١:٠٠ ص	43	69	58.7	808.02
١١:١٥ ص	47	72	59	812.1
١١:٣٠ ص	48	73.5	58.2	801.22
١١:٤٥ ص	49.5	75	59.2	814.82
١٢:٠٠ ص	50	76	59	812.1
١٢:١٥ ص	52	77.5	60	825.7
١٢:٣٠ ص	55	77.6	60.8	836.58
٠١:٠٠ ص	54	76	56.5	778.1
٠١:٣٠ ص	53	78	50.4	695.14
٠٢:٠٠ ص	54	74	47	648.9


Ti (° C)
Ti (° C)
60
50
40
30
20
10
0
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11:45 AM
12:00 AM
12:15 AM
12:30 AM
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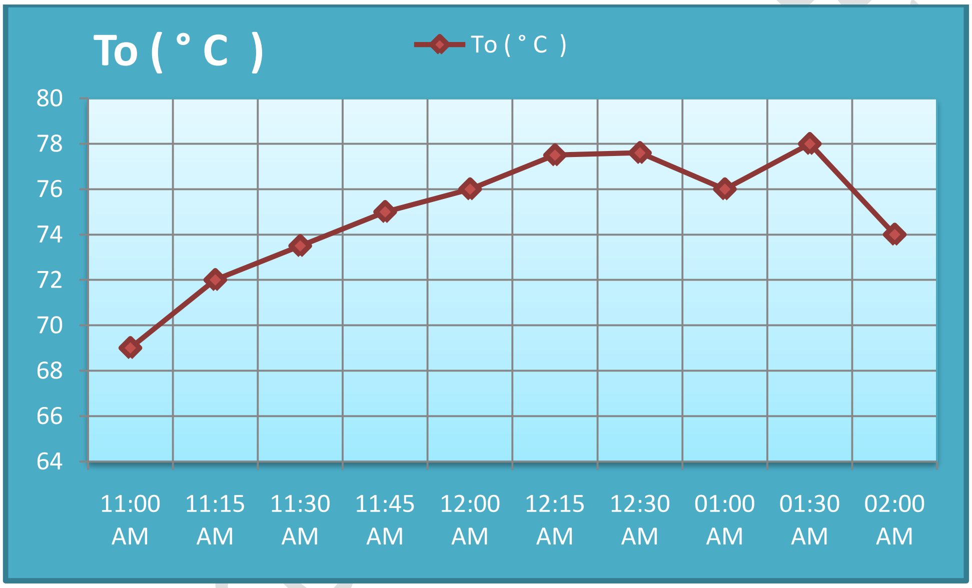
To (° C)
To (° C)
80
78
76
74
72
70
68
66
64
11:00 AM
11:15 AM
11:30 AM
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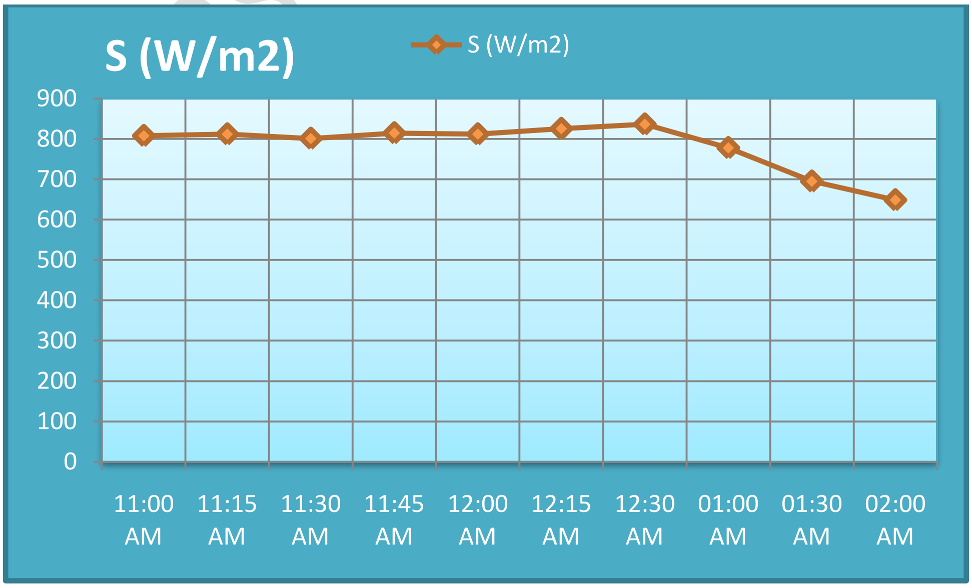
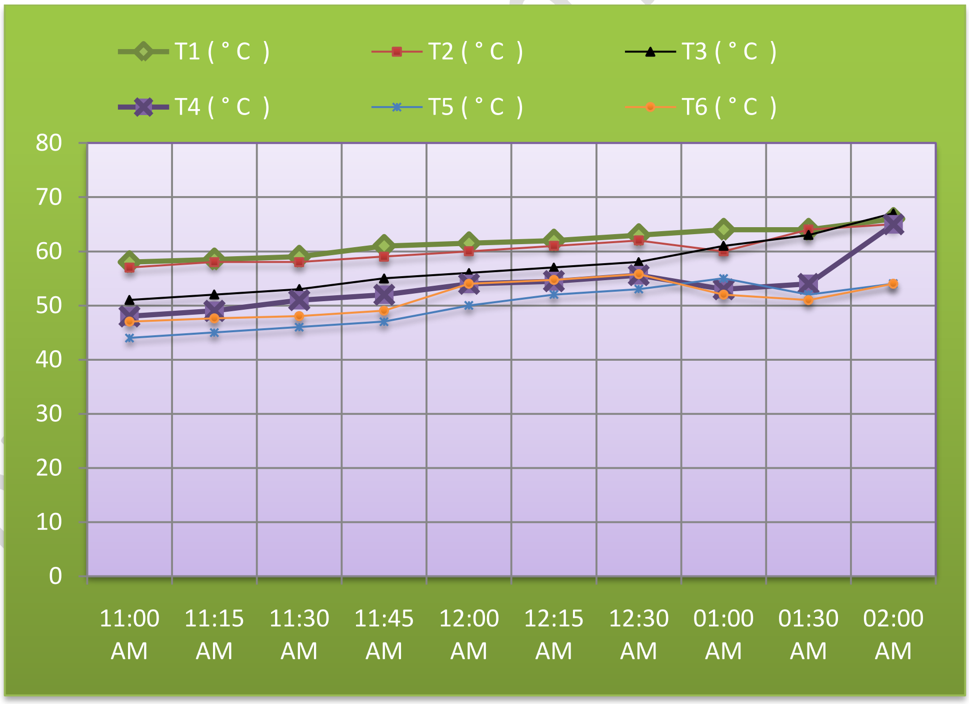

S (W/m2)
S (W/m2)
900
800
700
600
500
400
300
200
100
0
11:00 AM
11:15 AM
11:30 AM
11:45 AM
12:00 AM
12:15 AM
12:30 AM
01:00 AM
01:30 AM
02:00 AM

In the first PCM start melting

TIME	T1 (°C)	T2 (°C)	T3 (°C)	T4 (°C)	T5 (°C)	T6 (°C)
١١:٠٠ ص	58	57	51	48	44	47
١١:١٥ ص	58.5	58	52	49	45	47.6
١١:٣٠ ص	59	58	53	51	46	48
١١:٤٥ ص	61	59	55	52	47	49
١٢:٠٠ ص	61.5	60	56	54	50	54
١٢:١٥ ص	62	61	57	54.5	52	54.7
١٢:٣٠ ص	63	62	58	55.6	53	55.8
٠١:٠٠ ص	64	60	61	53	55	52
٠١:٣٠ ص	64	64	63	54	52	51
٠٢:٠٠ ص	66	65	67	65	54	54

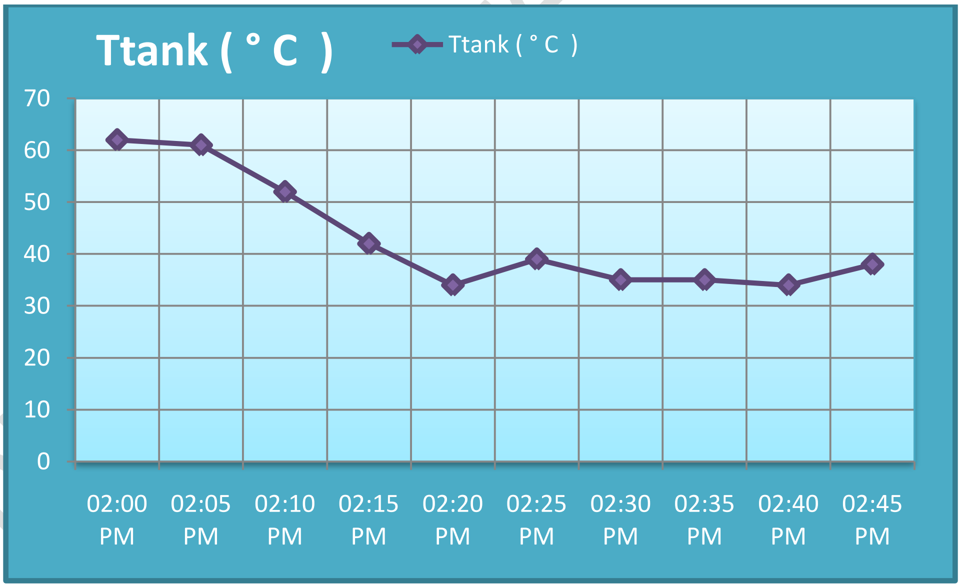


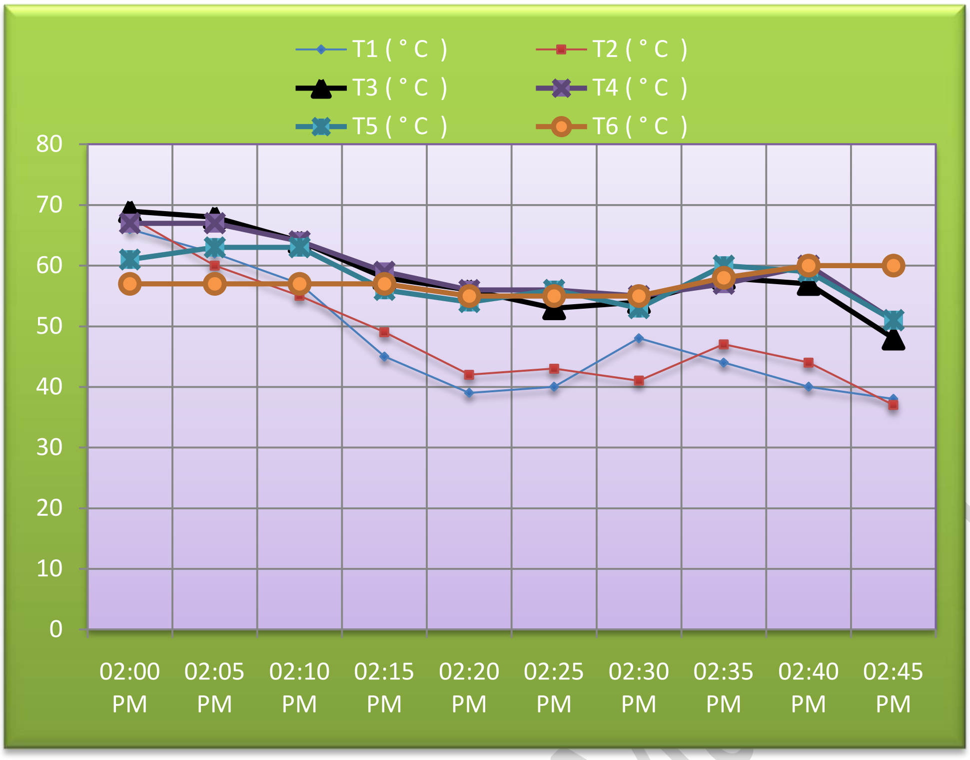
Now we will make discharging of hot load and study solidification of PCM and we can obtain Q_u & η during this process:

we replace hot water by cold water from the source till we reach the source temperature inside the storage tank. We find that temperature of water inside tank reaches 32°C (source temperature)

after discharging about 45 liters of water. During this process PCM is solidifying and losing its thermal energy to the flowing water.

TIME	Ttank (° C)	T1 (° C)	T2 (° C)	T3 (° C)	T4 (° C)	T5 (° C)	T6 (° C)
٠٢:٠٠ م	62	66	68	69	67	61	57
٠٢:٠٥ م	61	62	60	68	67	63	57
٠٢:١٠ م	52	57	55	64	64	63	57
٠٢:١٥ م	41	45	49	58	59	56	57
٠٢:٢٠ م	34	39	42	56	56	54	55
٠٢:٢٥ م	39	40	43	53	56	56	55
٠٢:٣٠ م	35	48	41	54	55	53	55
٠٢:٣٥ م	35	44	47	58	57	60	58
٠٢:٤٠ م	34	40	44	57	60	59	60
٠٢:٤٥ م	38	38	37	48	51	51	0





$$Q_u = Qw = \dot{m}_w * C_{p,water} * (T_{tank,avg} - T_s)$$

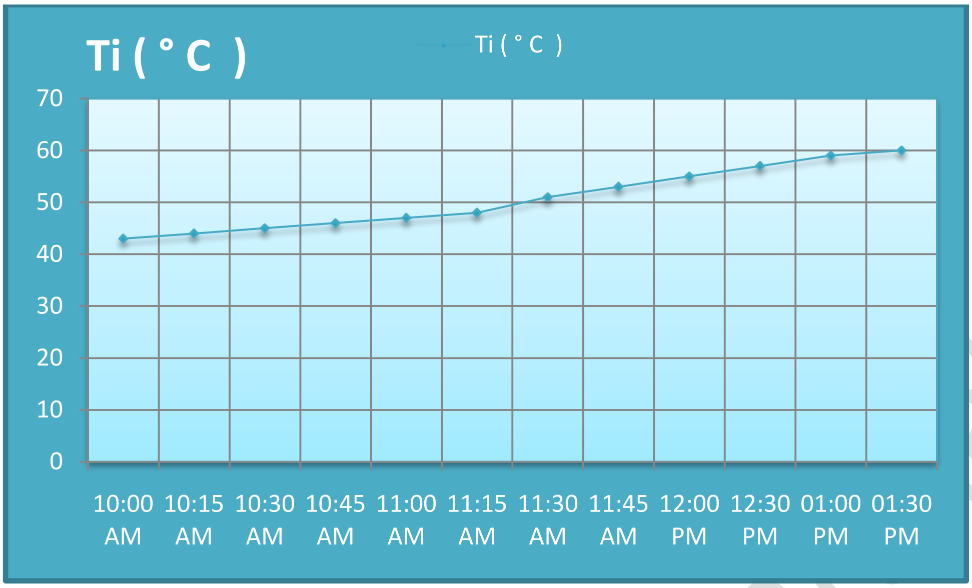
$$= [(45*0.001*1000)/(45*60)]*4180*(51-32)$$

$$=1323 \text{ j}$$

4.4.6- Day 4(11/6/2012) – Angle 30^o for water with 4 PCM capsules of concentration zero Aluminum powder together inside tank:

TIME	T_{amb} (°C)	$T_{plate,pipe}$ (°C)	$T_{plate,fin}$ (°C)	T_{tank} (°C)
١٠:٠٠ ص	28	50	59	38
١٠:١٥ ص	28	58	60	39
١٠:٣٠ ص	37	59	60	42
١٠:٤٥ ص	37	59	61	45
١١:٠٠ ص	37	60	62	53
١١:١٥ ص	36	61	62	59
١١:٣٠ ص	38	63	64	62
١١:٤٥ ص	42	65	64	64
١٢:٠٠ م	40	68	70	66
١٢:٣٠ م	39	69	70	68
٠١:٠٠ م	39	70	72	70
٠١:٣٠ م	38	69	72	71

TIME	T_i (°C)	T_o (°C)	S (mv)	S (W/m2)	T_{tank} (°C)
١٠:٠٠ ص	43	51	46.9	647.54	38
١٠:١٥ ص	44	54	51.2	706.02	39
١٠:٣٠ ص	45	58	57.1	786.26	42
١٠:٤٥ ص	46	58	58	798.5	45
١١:٠٠ ص	47	60	57.7	794.42	53
١١:١٥ ص	48	61	56.8	782.18	59
١١:٣٠ ص	51	63	59.4	817.54	62
١١:٤٥ ص	53	70	59.8	822.98	64
١٢:٠٠ م	55	77	58.7	808.02	66
١٢:٣٠ م	57	78	57.7	794.42	68
٠١:٠٠ م	59	79	54.8	754.98	70
٠١:٣٠ م	60	80	52.3	720.98	71


Ti (° C)
Ti (° C)
70
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50
40
30
20
10
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10:00 AM
10:15 AM
10:30 AM
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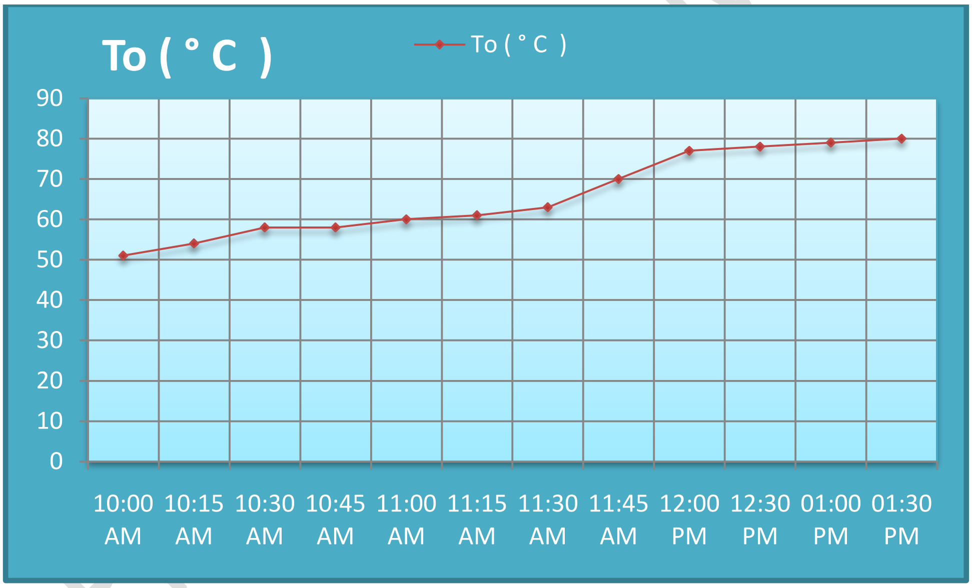
01:30 PM


To (° C)
To (° C)
90
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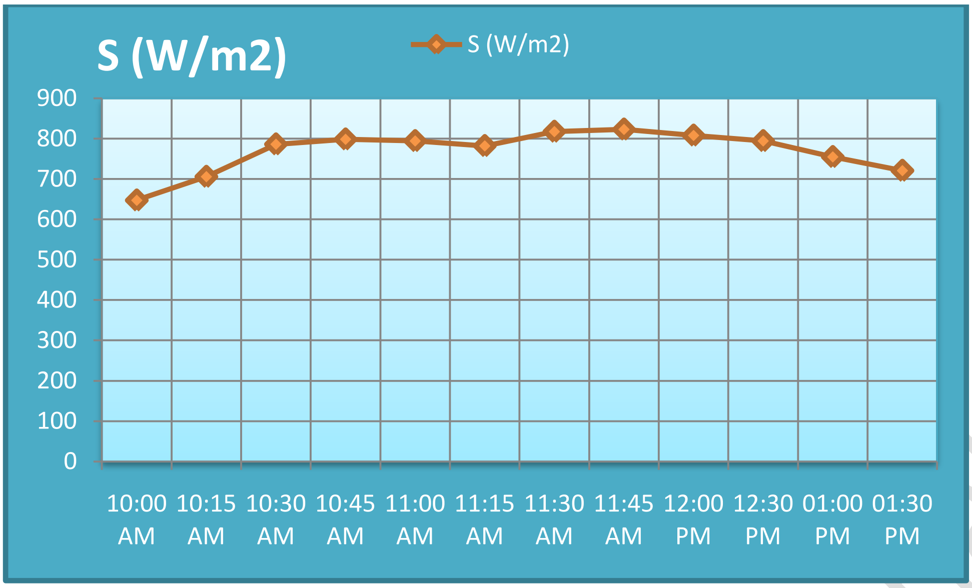
S (W/m2)
S (W/m2)
900
800
700
600
500
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300
200
100
0
10:00 AM
10:15 AM
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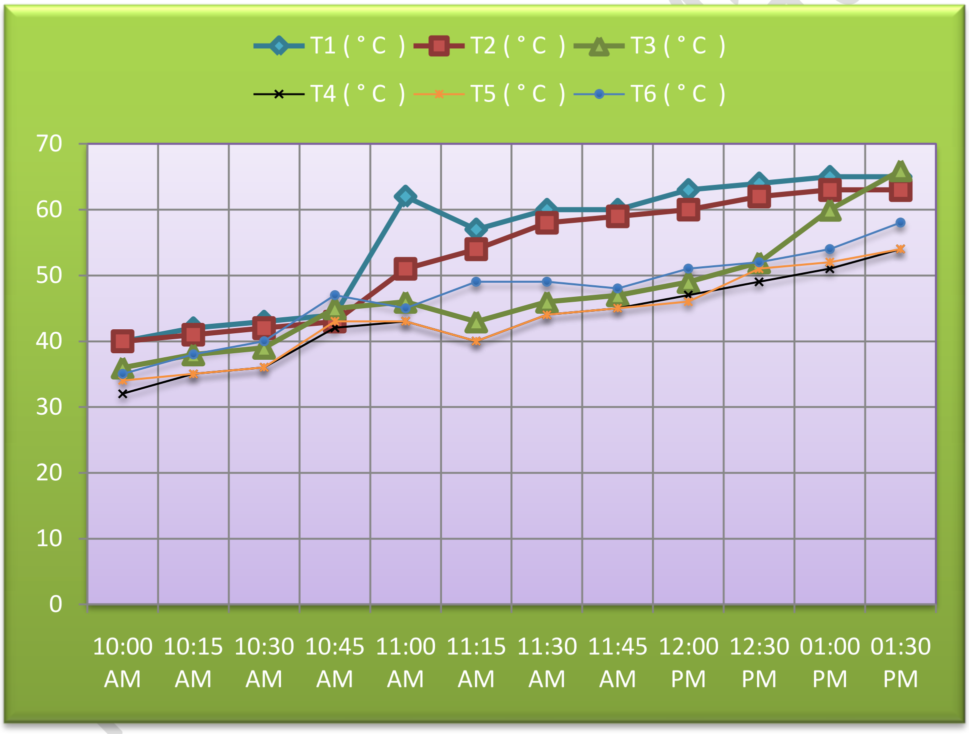
01:30 PM


T1 (° C)
T2 (° C)
T3 (° C)
T4 (° C)
T5 (° C)
T6 (° C)
70
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10:00 AM
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4.5 conclusion

From the results we can see the effect of using paraffin wax on the performance of the system and the useful heat gain.
Using PCM increase the amount of heat storage &useful heat gain .
Paraffin wax store heat energy by two methods (sensible and latent) which increase heat stored in it.But paraffin wax has low conductivity ,we icrease it by adding alimanum powder by different weights and calculate the effect of it in the conductivity of the the paraffin wax , this affect the amount of heat storage in paraffin wax.