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Experimental Verification of Decreasing Charging Time of Tes System Using U and W Tube.

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ABSTRACT: In this thesis , there is a experiment is performed on two designs of tube system for TES. Thermal energy storage system includes the use paraffin wax as PCM and water is used as the heat transfer fluid [HTF]. Charging time of the two cases are studied and as a result case(ii) W tube TES system take 12 min less than i.e. it takes about 14% less time than the case(i) U tube. In this experiment , heat transfer coefficient of w tube is about 3% greater than u tube that proves W tube has better heat transfer property. Contact area of w tube system is more than u tube , that effect the charging of TES system and reduces its time. Resistance in w tube system is less than the u tube because convective heat transfer coefficient is greater in w tube. Rayleigh number and nusselt number is also calculated to check the free or natural convection in the system, that also gives a favourable result in support of W tube thermal energy storage system. Loss in the heat of water inlet and outlet must be equal to the heat transfer to the PCM from the tube, taking the latent heat storage working as thermal isolation. Heat transfer in w tube about 3.6% is more than u tube, as the design of w tube is better than that of u tube. Main point is to check that how much is system is effective and from the results of the experiment w tube is 14% more effective than the u tube system. And the finally talking about the how much our system is efficient, w tube system is about 6% more efficient than the u tube system. Therefore this experimental can be further used for different enhancing process of Thermal energy storage system.

CHAPTER 1

1.1 INTRODUCTION

Energy, it has different defination according to its use. In physical world it is a quatitative property which can be trasferred from one system to another in different forms. Everything revolves around its definition, our day to day life runs on different energy resources that we consume according to our feasibility. As the energy demands increases, production of energy increases but there is limitation of the fossil fuel in the nature. Due to excess use of conventional energy some environmental problems arises such as ozone depletion, global warming e.t.c. as burning of these fuels harmful gases produced that are not good for environment as well as living beings. So world moves towards different technologies to use the clean and renewable energy resources i.e. sunlight, wind, tides, nuclear. During this industrial revolution period these energy sources are the only great option for development of the living being. As these sources are not going to extinct, can be used as much as our energy demands increases. Above energy resources are classified in two patrs i.e. conventional and non-conventional energy resources, energy that can not be used again once utilised are conventional. Energy sources that are used again are non-conventional energy resources. Solar is the one of the promising source of energy that are present abundantly in the atmosphere. The International energy agency estimated that in future solar energy will play a vital role in energy production. But the problem of solar energy is that it varies from day to day, location to location and season to season. There storage of these energy is required and it take some machinery and systems. These systems are also known as thermal energy storage system. Some of the technologies which are being used to use and increase the efficiency of the resources are discussed below shortly.

1.2 TECHNOLOGIES USED

These energy resoures can be extracted by different techniques available now days. As there are renewable source of energy and can be used again.

Some of the technologies are below:-

a) Solar cells.
b) Wind mills.
c) Tidal energy generators.
d) Nuclear reactors.
e) Geothermal well heat exchanger.
f) Hydropower system.

These technologies are used to extract energy available in nature. These methods are used to increase the efficiency of the energy sources , so that it can be used to run different types of industrial equipment. Energy that are produced in the industries during running their machines and different types of cooling system. These waste energy are released to the environment directly, that can also be used in storing energy in different forms. Definition of the waste energy, energy rather in the form of hot air(exhaust gas) or cooling fluid which are produced in power producing plants [1]. Both sensible heat and latent heat is considered as heat source.

To use this waste heat from the machines/devices, TES(Thermal energy storage) system have been developed. It is a system which follows three steps charging,storing and discharging. In this system energy is stored using some medium so that it can be used later [2]. Its process is shown below:-

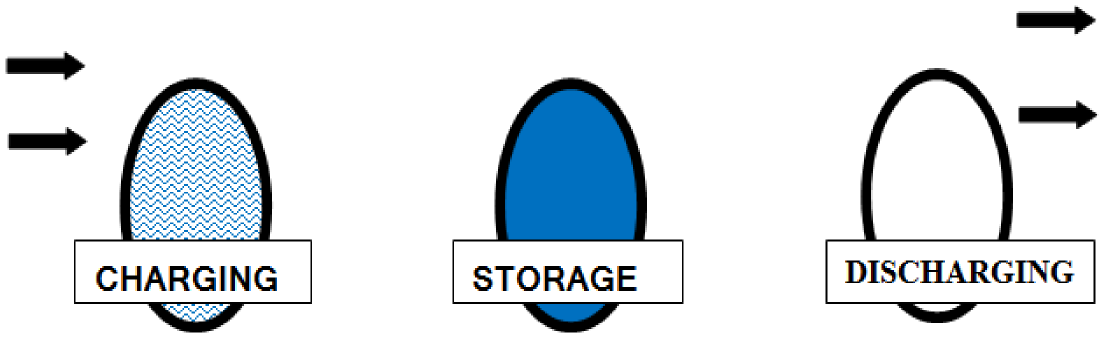

Fig.1.1 Process of TES system

TES system is not alone in this process, it needs a material medium to get sensible heat in and store in form of latent heat which can be further used according to need. This material medium is called PCM(phase change material), these are material which have low melting point temperature similar to the waste heat temp. that we get from industries. They store the heat and discharge when it is used. In this context it also been consider the fluid which takes heat and transfer it to the pcm i.e. called HTF(heat transfer fluid).

There is many types of PCM such as organic and inorganic, their selction criteria must be done properly. In the same way HTF can be air, oil, molten salts [3]. Therefore selection of different equipments and material is important. TES system has different disadvantages such as:-

i. In begining of charging the process is slow.
ii. Low conductivity of TES material.
iii. Early discharging due to heat loss.
iv. Mainly expensive due to high technologies.

To overcome such problem different efforts are applied to make it more cost efficient and enhanced. Others measures are also taken to solve all the problem realated selection of pcm and heat transfer fluids, and to make them more effective. Now to make the thermal energy storage sysmtem more efficient and enhanced the heat storage capacity of the PCM, different experiments and numerical simulation was done. According to the energy demands and cost efficient condition methods are applied to increase the efficiency of the system. Considering these technologies for utilising waste heat energy storage, differnt research paper presented by different author. Survey is done by going through different content which is presented here, literature review

1.3 LITERATURE REVIEW

For heat storage, latent heat storage system with phase change material is most effective method, as this system has high energy density in comparison to sensible heat storage system because they require low volume for storing more energy than other [4]. Paraffin wax has all feasible thermo-physical properties to be used in any latent heat storage system as its melting point is lie aroumd 51-59^{o}C , its charging and discharging time is suitable as required, Thermochemical are those in which chemical reaction produces heat, in sensible heat storage single phase storage is done to increase the heat and latent heat storage deal with the solid-liquid phase change[5]. Water is the non-metallic fluid which have high thermal conductivity in comparison to the other fluids and its also intoxic, no flammable therefore water can be used as good heat transfer fluid for transfering heat. Now it has to make the system more efficient as its charging time is more, so to solve this problem many research paper has been published and survey of some papers are here. A theoretical model presented by gupta and roy [6] in which forced convection method used in circular duct of PCM slurry and Nusselt number of the slurry pcm is 1.5 to 2 times more than the fluid enhancing the heat transfer coefficient of the system. Such as to increase the conductivity of phase change material two different melting point PCM can be used in separate container of one having low melting point and other having high melting point [7]. Using phase change material as capsul form increases the heat transfer which can increase the efficiency of the thermal energy storage system but the latent storage system and the PCM capsule must be distinguish[8]. Material of shell in which the PCM should be filled can also affect the heat transfer coefficient of the system and their fabrication is explained by jacob [9] in which different materials withstand the encapsulated PCM . Adding nano particle in the phase change material in different volume increases the melting rate of PCM which can enhance the storing capacity and can decrease the charging time of thermal energy storage system[10]. Different composite PCM was used to enhance the system lauric acid/modified sepiolite is used which shows increase in thermal conductivity to 0.59 w/mk, higher than the prestine LA so that it can be used in building field Qiang shen [11]. In indonesia production of coconut is very high therefore using coconut oil as PCM, is a promising experiment which can be used as good alternatives as it decrease the cooling temperature by 1^{o}C/kg presented by widya A putri [12]. Design of the container of TES system must follow some data such as inlet and outlet temperature, physical properties of other materials such as heat transfer fluid and phase change material used. Size of tubes inserted to flow HTF must be discussed and their thickness. Container diameter are also in the range for increasing thermal conductivity of the PCM[13]. Thermal energy system divided in to three different types i.e. thermochemical storage system, sensible heat storage system, latent heat storage system, different characteristics of phase change material is also explained by A.Abhat [14]. Different methods are applied to increase the heat transfer in the latent heat storage system is to have some extended surface or fins to the system, so that thermal coductivity should increased and by changing the geometrical configuration also increases the heat transfer. Heating pipes are also introduced to increase the thermal conductivity by contacting the phase change material [15]. Different organic phase change material such as lauric acid, paraffin and stearic acid is compared to investigate the energy and exergy, results comes that lauric acid has the better energy storage presented by yadav and sahoo [16]. Generally PCM melting point below 100^{o}C is considered but choi and kim [17] uses $MgCl_2.6H_2O$ which has 116.7^{o}C melting point is used in 5 finned tube and 10 finned tube, resulting that there is not much difference in between their efficiencies but gives 25% better result than Utube. Composite slab of PCM having different melting point temperature is used in different shells which have 2PCM & 3PCM, numerical experiment was done by gong and mujumdar [18] shows that thermal conductivity is enhanced by 31.7% when the ratio of liquid and slab is 0.1. Paraffin is the most promising PCM which had many desirable properties such as latent heat of fusion, negligible supercooling and it have high potential for low thermal storage application, review by hasnain[19]. Combined study by zheng [20] using 1-dimensional physical model neglecting the sensible heat using finite different method to simulate the latent heat, as a result decrease in phase change time by 25-40% of composite PCM. Using metal matrix in PCM, using fins and creating steam bubble in tube for enhancing the thermal conductivity is presented by velraj and faber[21] which resulted that there is enhancement of 10 times increase in thermal conductivity and volume of PCM also decreased by 20%. Mathematical model given by horbaniuc and dumitrscua [22] for the study of solidification within a longitudinal fin heat pipe latent heat TES system,parabolic and exponential approximation done for different number of fins,results that increasing no. of fins decreases the charging time. Parametric study by wang and yap [23] of PCM based hybrid heat sink, it stabilizes the local temperature at the desired value if PCM is not melted fully,increases the free convection for appropriate PCM. Use of bio-based PCM which contain soybean oils,coconut oils and beef tallow with graphite nanoplatelets show that thermal based bio PCM has 75% more latent heat than the pure bio based PCM and using graphite platelets enhanced the thermal resistance of bio based PCM et al.[24]. Numerical simulation was done by kurnia,sasmito,jangam, mujumdar et al.[25] to change the geometrical design variation on tube,which results that changing the design of tube can enhance the system performance by 30% and also enhances the discharge rate by 50%.

CHAPTER 2

2.1 SELECTION OF MATERIAL

i) PCM(phase change material)

Selection of phase change material should be done on their thermophysical properties. Their main problem is that thermal conductivity is very low.Melting point of the phase change material should be low so that the charging time must be minimum as much it can. Specific heat capacity of the material should be high to store the heat in maximum energy/volume. Latent heat of fusion

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must be more as much it can but this property of the PCM is depend on their crystal structure. These are some important properties of the PCM which should taken care while selecting PCM. So by going through different research paper and considering the property & availability of phase change material Paraffin wax is used in this, whose thermophysical property is given in Table 1.

i) TES SYSTEM

Thermal energy storage system is basically depend on the material of construction , it includes a container which must have low thermal conductivity or must be perfectly insulated. It should not react with phase change material filled in it and withstand the melting temperature of pcm. It should be cost efficient and easily available. In this latent heat storage system solid-liquid phase is used to store the heat energy. Therefore design methodolies are consider such as effectiveness-NTU, LMTD, convective heat transfer coefficient e.t.c. Therefore latent heat storage TES system made up of stainless steel is used.

ii) HTF(heat transfer fluid)

Fluid which carry heat with them and travel in a conducting tube around the phase change material in the thermal energy storage system are known as HTF. Thermal conductivity should be high of the fluid, generally they have low thermal conductivity in comparison to metals. Generally water is used as the HTF due its better thermal conductivity and easy availability, it makes the system more cost efficient also. Water will be used as for the cost efficient and easier to operate for TES system. Its relation for thermo-physical property is given by the sasmito and kurnia [26].

CHAPTER 3

3.1 DESCRIPTION OF EXPERIMENTAL SETUP

Water that is use as HTF , heated in a 10 litre cpacity well insulated (asbestos rope) tank which is made up of stainless steel . For heating purpose heating coil is used which heated the fluid to a temperature of 70^{o}C . Its temperature is maimtained at same with the help of temperature controller. HTF is pumped to TES system from tank with the help of a magnetic pump. Its pumping capacity is controlled by a regulator dimmer.Rotameter is used for measuring the flow of HTF. A digital thermometer is used in tank to check the temperature of fluid so that flow should start at 70^{o}C. Two more digital thermometer is placed in the HTF flow tube before entering and leaving from TES system.

In TES system in which there is a Stainless steel container having inner diameter 14 cm and 1.10 mm thickness which is perfectly insulated with the Glasswool. Container is filled with PCM (paraffin wax)the thermophysical property of PCM is given in table. 1. There is a stainless steel tube of inner diameter 1.27cm and 1.10mm thickness in which HTF (water) flow. The tube install in TES system by U and W design as shown in Fig.**3.1** .

In TES system 7 calibrated digital thermometer with range -50 to 70^{o}C with uncertainity 0.25-0.40%. It is placed in container in axial and radial loction as seen in Fig.**3.2**. and their distances from the wall is given in table.**3.2** . The schematic diagram of experimental setup as shown in **Fig.3.1**

Table. 3.1. Thermo-physical properties of paraffin wax and experimental values [27].

Thermo-physical properties	**Experimental values**
Melting Temperature (T_m) ^{o}C	52-57
Thermal conductivity (K)[W/mK]	0.15-0.24
Density (ρ) [Kg/m^3]	810.5$_{(s)}$771$_{(l)}$
Specific heat (c_p) [KJ/KgK]	2.384$_{(s)}$, 2.89$_{(l)}$
Latent heat of fusion [KJ/Kg]	173.4
Dynamic viscosity(μ) [N.s/m^2]	6.3×10^{-4}
Kinematic viscosity(υ) [m^2/sec]	8.31×10^{-5}

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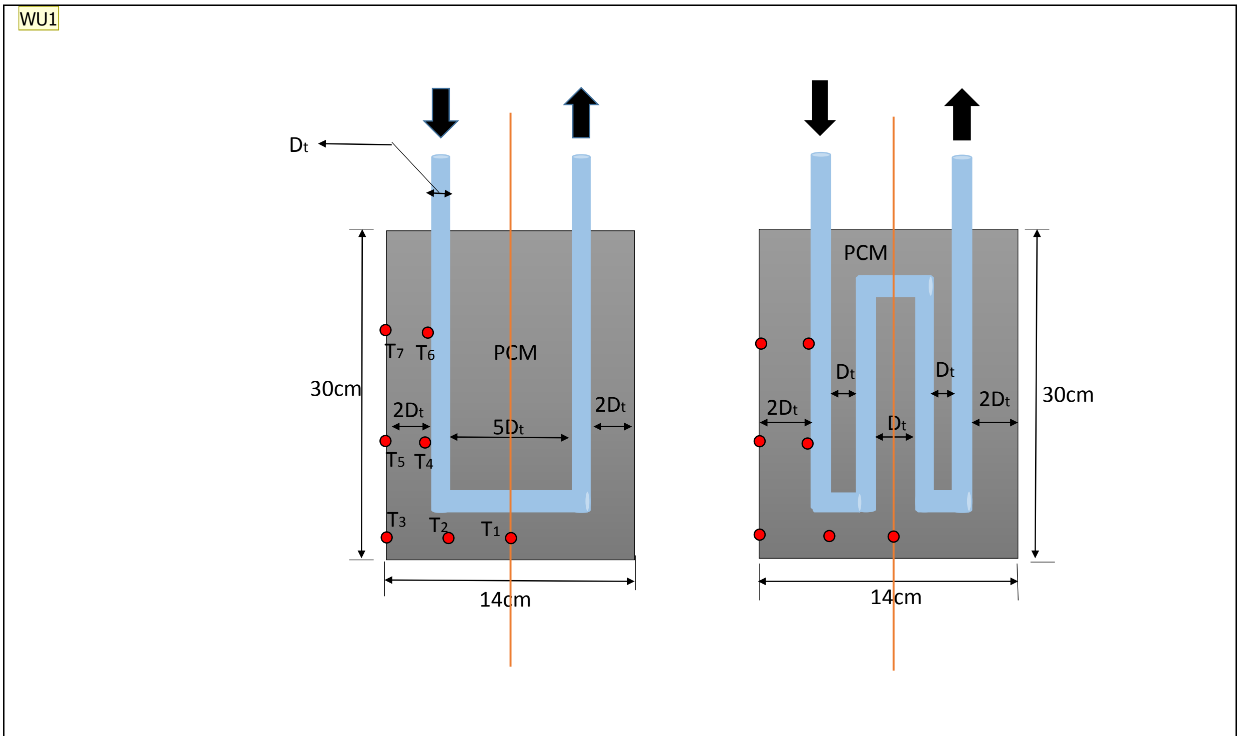

Fig.3.1 Schematic diagram of TES system

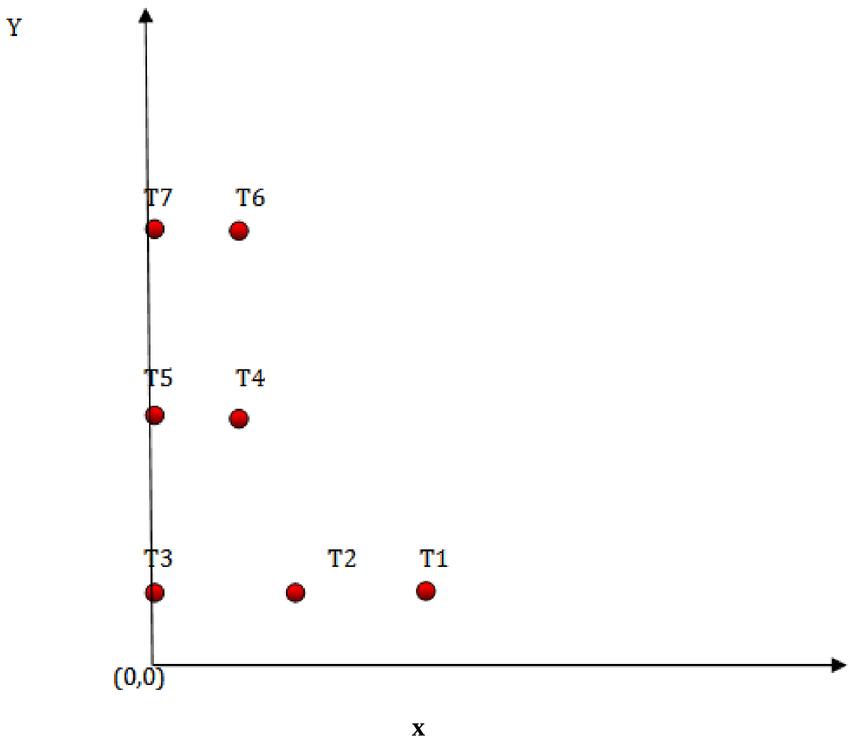

Fig. 3.2:- Position of Thermocouple.

Table 3.2 Distance of Thermocouple from container wall.

S.No.	Thermocouple	X	Y
1	T1	7cm	1.27cm
2	T2	3.5cm	1.27cm
3	T3	0cm	1.27cm
4	T4	2.54cm	11.27cm
5	T5	0cm	11.27cm
6	T6	2.54cm	21.27cm
7	T7	0cm	21.27cm

3.2 PROCEDURE OF EXPERIMENT

Water is heated at 70^{o}C in the tank with the help of heating coil. Then it is pumped to the TES system. Flow is maintained at 2 lpm measured by the rotameter.

A. **Case I container with U tube arrangements**.

When flow starts inlet T_i and outlet T_o of HTF is noted. This step is repeated in a time interval of 10 min until the T_i and T_o of HTF reaches same or uniform temperature. During every 10 min time period all the temperatures of the 7 thermometer located at different positions should be taken. These datas are used to plot graph between the time and temperature variation during the process. When uniform temperature achieved its shows that the TES system is charged. Schematic diagram of U tube TES system is shown in Fig.3

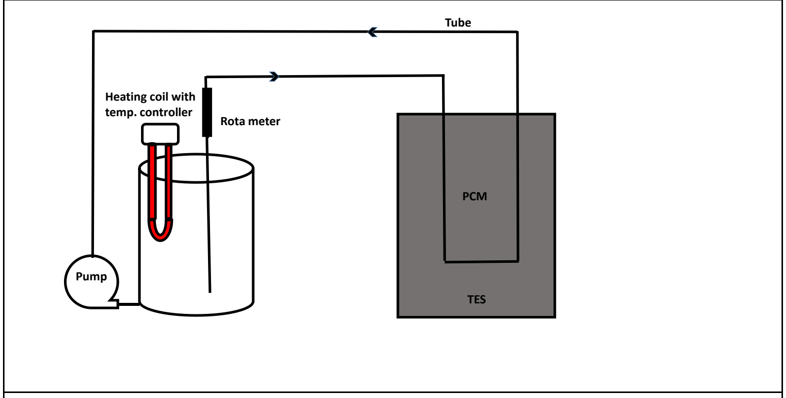

Fig.3.2.1 Schematic diagram of U tube TES system

B. **Case II container with W tube TES system.**

Same procedure is followed in this case also that was done in the case I. In this case it is observed that the charging of TES system takes less time than U tube. Schematic diagram of W tube TES system is shown in Fig. 4.

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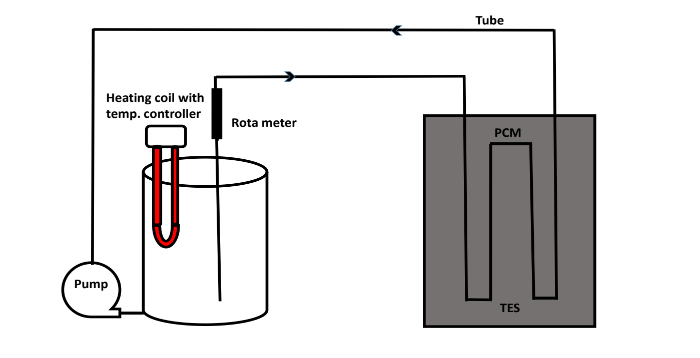

Fig.3.2.2 Shematic diagram of W tube TES system.

3.4 THERMAL EVALUATION OF EXPERIMENTAL SETUP

The thermo-physical properties of water are given as functions of temperature. The density, viscosity, thermal conductivity and specific heat of water are defined as kays [26].

ρ_w = -3.570×10^{-3} T^2 + 1.88T +753.2,

μ_w = 2.591×10^{-5} × 10$^{238.3/T-143.2}$,

k_w = -8.354×10^{-6} T^2 + 6.53×10^{-3}T – 0.5981,

Cp_w = 4180.

CALCULATION

Heat loss by the water going through the tube can be calculated by the given equation. How much heat given by water through a fix flow rate 2 lpm.

Q [kw]= $\dot{m}_w \times C_{pw}[T_{wi} - T_{wo}]$

(3.4.1)

Amount of mass flow per sec is given by the following formula

$\dot{m}_w$ [kg/sec]= ρ_w×lpm×0.000017

(3.4.2)

Amount heat exchange between the water and the wall of the tube can be found by the given equation.

Q [kw] = K×A×θ

(3.4.3)

LMTD of the system-

$$\theta = \frac{T_{wi} - T_{wall} - [T_{wo} - T_{wall}]}{\ln\frac{[T_{wi} - T_{wall}]}{[T_{wo} - T_{wall}]}}$$

(3.4.4)

Internal heat transfer resistance is given by

$$R_{in} = \frac{1}{\pi d_i l_t h_{in}}$$

(3.4.5)

Resistance of heat transfer ouside the water tube is calculated using equation.

$$R_O = \frac{1}{\pi d_o l_t h_o}$$

(3.4.6)

Wall resistance of the stainless steel tube is calculated by the following equation.

$$R_{wall} = \frac{\ln\left(\frac{d_o}{d_i}\right)}{2\pi l_t K_w}$$

(3.4.7)

Overall resistance of the TES system is

$$R_{overall} = R_{in} + R_o + R_{wall}$$

(3.4.8)

Internal convective heat transfer coefficient is

$$h_i = \frac{N_u \times K_w}{l_t}$$

(3.4.9)

Outer convective heat transfer coefficient is

$$h_o = \left[\frac{1}{k} - \frac{d_o}{h_{in} d_i} - \frac{d_o \ln\frac{d_o}{d_i}}{2k_w}\right]^{-1}$$

(3.4.10)

Calculation of overall heat transfer coefficient (K) equation[28]

$$K = \frac{c_{pw} \times \dot{m}(T_{wi} - T_{wo})}{\pi d_i \times l_{tube} \times \theta}$$

(3.4.11)

To calculate the rayleigh number of the fluid first grassoff number that is the ratio of buoncy force and viscous force.

$$G_r = \frac{g\beta l_t^{\,3}(T_{wi} - T_{wall})}{\upsilon}$$

(3.4.12)

Prandtl Number.

$$P_r = \frac{\mu_w \times C_{pw}}{K_w}$$

(3.4.13)

Rayleigh number is the product of grassoff and prandtl number of the fluid

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$R_a = G_r \times P_r$
(3.4.14)

If the rayleigh is between 10^4 to 10^9 then it is laminar flow and in this case we are dealing with laminar flow therefore Nusselt corelation for laminar is given below

$N_u = 0.59\,(R_a)^{\frac{1}{4}}$
(3.4.15)

Now we have to check the effectiveness of the system, so that it can be applied in the physical practice

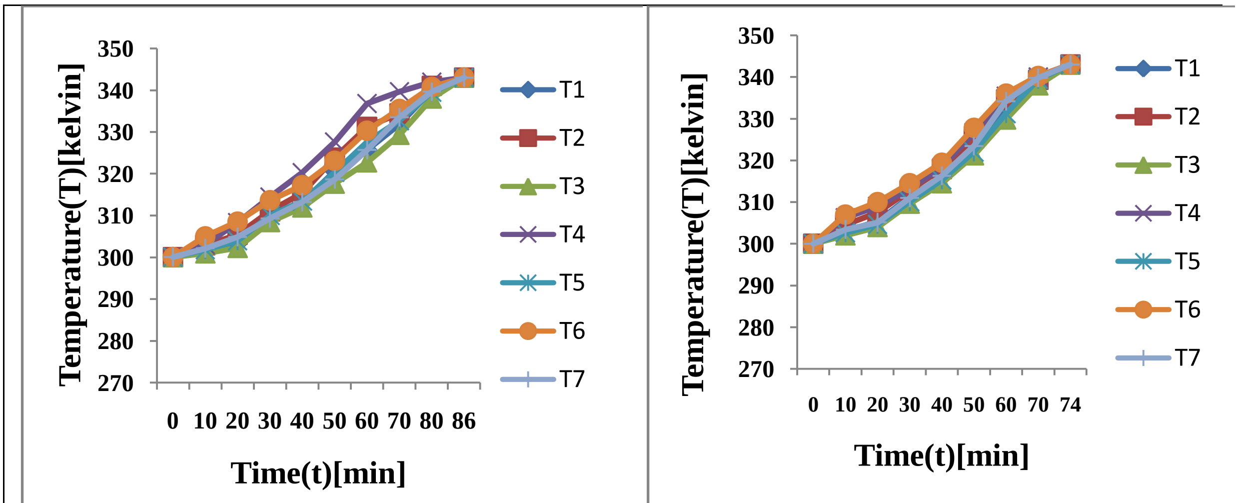
$\varepsilon = \frac{T_{wi} - T_{wo}}{T_{wi} - T_{wall}}$
(3.4.16)

Finally efficiency of the system, which define that how much our ehancement technique works.

$\eta = \frac{\text{Total energy stored in TES}}{\text{Energy input}}$
(3.4.17)

CHAPTER 4

4.1 RESULT AND DISCUSSION



Charging of Paraffin wax in U tube	Charging of Paraffin in W tube

Fig. 4.1 Temperature profile of TES system for case U tube and W tube with time.

A it is clear from graph that the charging time of the U tube is 86 min and on other hand W tube takes 74 min for charging. Temperature T4 is higher in the u tube and after that temperature of T6 is greater than other temperature profile. T4 and T6 is greater than other because it is located near the tube and other are located in between them as we clearley see in **Fig.3.1** T7 has very low temperature as it is far from the tube and due to gravity forces PCM settels at the bottom and temperature at the lower region is less than upper side.

In the same way temperature T6 is high as it located at the top and it comes twice in contact with tube and after that T4 has greater value. At the end due to uniformity temperature difference decreasing and everywhere temperature profile become same and hence PCM is charged.

It is clear that the W tube takes 12min less time in charging than U tube, therefore it is better option than U tube to be used for minimising the charging time for TES system. Now further we check different property of both the system below.

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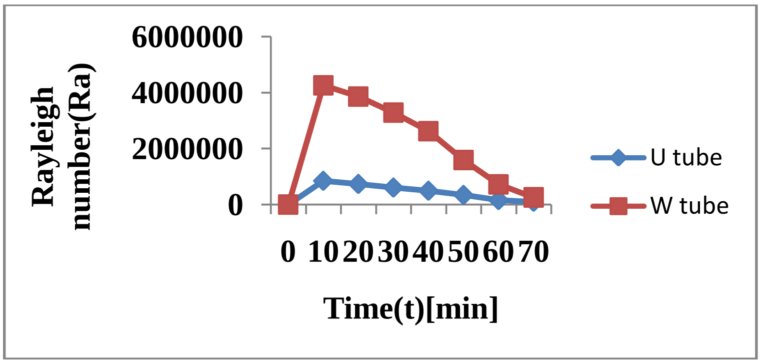

Fig.4.2 Rayleigh number of HTF with time.

Rayleigh number of the TES system lies under the range of $10^4 - 10^9$ therefore free convection justifies. Flow of the system lies between the range of laminar flow therefore all the realtion is used for laminar free convection. Rayleigh number in W tube is greater than U tube, hence free convection is more in the w tube that leads to the fast charging of the system. So we can use w tube than u tube for better convection heat transfer.

Nusselt of the system is also dependent on the rayleigh number and it also signifies the better system. If the value of rayleigh number goes below then there will be no fluid motion and heat transfer is by conduction rather than convection and from above we conclude that the heat transfer in the system is under free or natural convection.

Heat transfer due to free convection in w tube is greater than the u tube , therefore w tube latent heat storage system is more responsiv to the free convection and can be used for further application where convection heat transfer is applied.

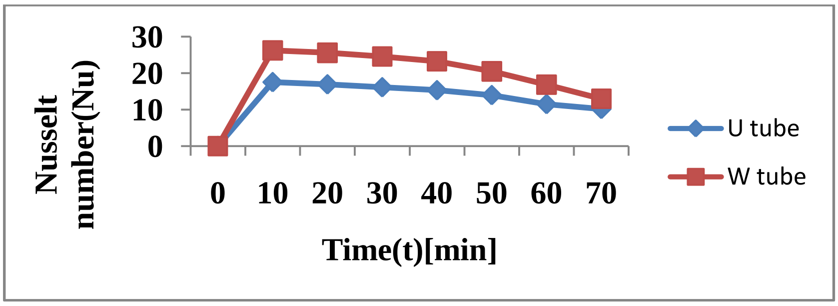

Fig.4.3 Nusselt number variation with time.

Nusselt number is the ration of heat transfer by conduction to the heat transfer by convection. It the dimensionless number , closely related to the rayleigh number. The convection and conduction heat flows are parallel to each other and to the surface normal of the boundary surface, and are all perpendicular to the mean fluid flow in the simple case. Nusselt number greater generally show that the convection is happen and from the figure it can seen that the value of nusselt number is more in W tube than U tube. Hence it show sthat more convection in the w tube than u tube.

Finally it can be said that there is more convection in W tube than the U tube , therfore w tube is a better option than the u tube for further use in TES system.

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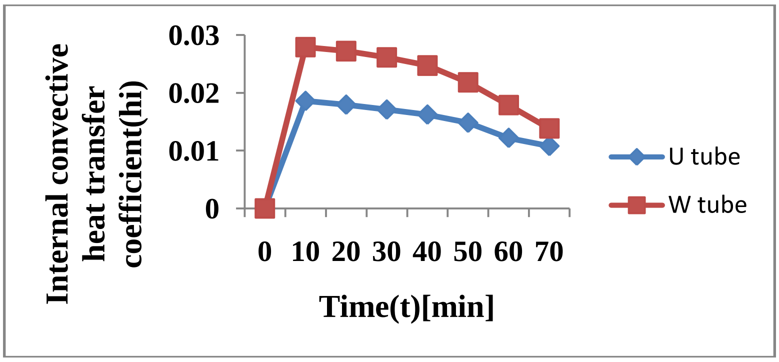

Fig. 4.4 Variation of interal convective heat transfer coefficient with time.

Heat transfer coefficient defines capacity of the system to trnasfer heat from different boundaries. In above graph it can be seen that in both the case heat transfer coefficient decreases with time. It is because in beginning temperature differnce is more between the system , as the time increses PCM started melting and the temperature decreases and hence heat transfer coefficient decreases.

In w tube heat transfer coefficient is more than the u tube and hence more heat transfer in w tube than u tube. So it shows that it will take less time to charge the system in w tube than u tube , therfore it is better TES system .

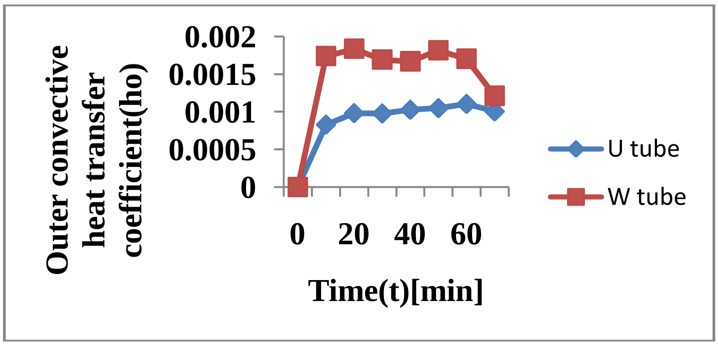

Fig.4.5 Variation of outer convective heat transfer coefficient with time.

Heat transfer coefficient outside the tube is also a major parameter to check the charging of the PCM. From above it can be observed tha the coefficient of heat ransfer is more in W tube that means there is more heat transfer in w tube that going to decrease the charging time of the TES system. Due to more area of tube comes under the contact of tube and thus more heat from the heat transfer fluid to the system ensures the fast charging of w tube.

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In final it can be said that both the heat transfer coefficient , inside or outside is greater in W tube than the U tube , therefore its gives a worth reason for consuming less time in charging of TES system using w tube. And hence it is better than u tube system

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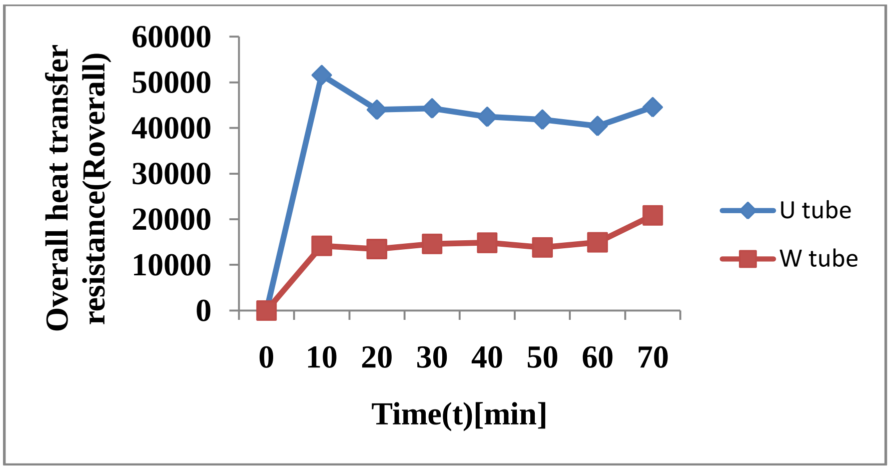

Fig. 4.6 Variation of overall heat transfer resistance with time.

Thermal heat resistance is a heat property and a measurement of temperature difference by which an object or material resist a heat flow. It is reciprocal of the heat conductance , it resist the heat transfer flow between the wall. If the heat transfer is greater then the resistance will be less and it shows that system has less obstacle in heat transfer. In beginning it is more as heat transfer obstacle due to less thermal conductivity but as it starts more heat transfer coefficient then goes on decreasing.

In u tube, resistance is more than the w tube TES system therefore it verifies that the w tube system is better than the u tube. As thermal heat resistance is more in u tube that decreases the heat transfer that increases the charging time of the system.

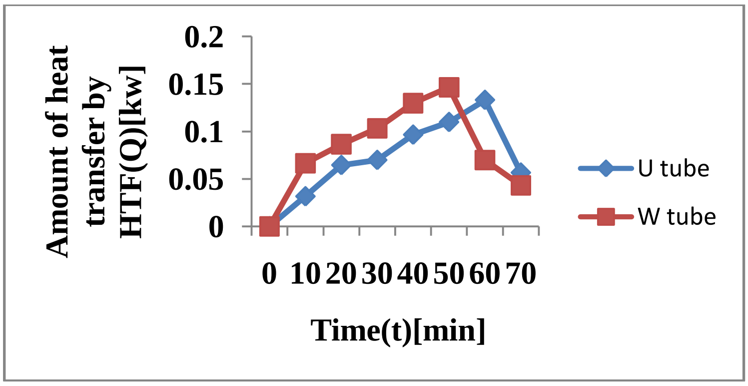

Fig.4.7 Amount of heat transfer by fluid.

Amount of heat transfer defines that the sytem is having good thermophysical property. From **Fig. 4.7** it is clearly shows that the heat transfer is increasing as time increases. Peak in u tube arises at 60 min where PCM is about to melt

Therefore it is clear that there is more heat transfer in w tube than the u tube TES system. And peak is also comes early of 10 min than the u tube and at that time heat transfer suddenly increases and after that it decrease as system doesn't need more temperature to charge. In the same way in w tube this peak of heat transfer comes early at 50 min than u tube and after goes on dcreasing.

in w tube, hence W tube will charge early in comparison to the U tube system.

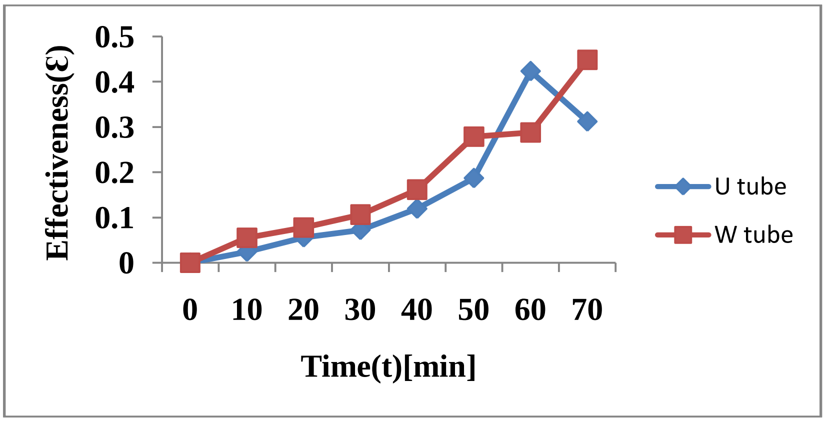

Fig.4.8 Effectiveness of the TES system.

Effectiveness is define as the ration of the actual heat transfer to the possible heat transfer in the system. It show that how much is the system is effective in practical application. From graph it is clear that w tube is 14% more effective than the u tube TES system , there from above result it is clear than W tube is far better in comparison to the U tube TES system and it gives 14% better effectiveness than the u tube system.

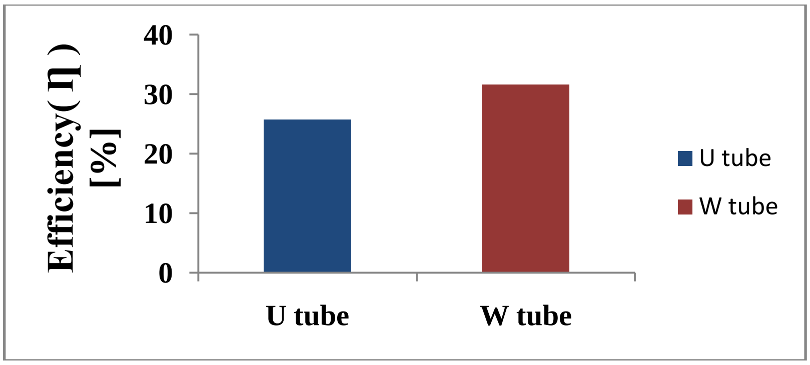

Fig.4.9 Efficiency of TES system.

Finally whole TES system discussion is going to end through by how much our system is efficient. This is done by comparing the efficiency of both the system , in which it shows that W tube TES system gives 31.6% efficiency on the other hand U tube system gives 25.7% .

Therefore w tube is about 6% more efficient than u tube , which is a great deal in science for energy storage.

4.2 CONCLUSION

From above experiment and the data comes in the result of that experiment shows here:

- Heat transfer coefficient, both internal and outer is more in W tube than U tube by 3%. That concluded that W tube system has better heat transfer.
- Amount of heat transfer is also more in the W tube in comparison to the U tube at peak time is 3.6% more. Therefore w tube system posses better heat transfer.
- Talking about the effectiveness, w tube is about 14% more effective than the u tube system.
- At last efficiency of w tube system is 6% more efficient than the u tube system.

4.3 FUTURE APPLICATION

This TES system can be further use with different PCM , by mixing two PCM with each other and then applied to W tube system.

Using nano particle in the PCM can also increase the efficiency of the system and further can decrease the charging time of the system.

This design of W tube can also be enhanced by usinf fin type W tube , so there would be more heat contact surface. But the orientation of fins can play a measure role in the contant surface of PCM heat transfer.

LIST OF SYMBOLS , ABBREVIATIONS AND NOMENCLATURE
NOMENCLATURE

C_p	Specific heat [kj/kg.k]
d	Tube diameter[m]
l	Tube length[m]
A	Heat transfer area[m^2]
h	Convective heat transfer coefficient[kw/m^2.k]
K	Overall heat transfer coefficient[kw/m^2.k]
ṁ	Mass flow rate[kg/s]
Nu	Nusselt number
Pr	Prandtl number
Q	Heat transfer rate[kw]
R	Convection thermal resistance[kelvin/kw]
U_R	Uncertainties
T	Temperature [k]
K_w	Thermal conductivity of water[kw/m.k]
t	Time [min]

ABBREVIATION

TES	Thermal energy storage
PCM	Phase change material
HTF	Heat transfer fluid
lpm	Liquid per minute

Greek Symbol

Ƞ	Efficiency
θ	Logarithmic mean temperature difference[LMTD]
Ɛ	Effectiveness
υ	Kinematic viscosity[m^2.s]
ρ	Density[kg/m^3]
µ	Dynamic viscosity[N.s/m^2]

Subscript

w	Water
w_{in}	Inlet water
w_o	Outlet water
wall	Tube wall
in	Inside tube
o	Outside tube

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