Journal of Engineering and Applied Sciences 13 (22): 9577-9581, 2018
ISSN: 1816-949X

Investigation Study on Heat Transfer of Paraffin Wax for Solar Energy Applications

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Abstract: Solar energy is a renewable energy source that can generate electricity, provide hot water, heat for houses and lighting for buildings. Paraffin wax is cheap and has moderate thermal energy storage density. Commercial paraffin wax grade A was used as Latent Heat Storage (LHS) is placed in a vertical cylindrical Heat Storage Container (HSC) and a central single pipe through which cooling water is passed for heat exchange from down to up of the HSC. Heater resistance tape placed outside the container used for supply the heating to wax. In this setup, the phase change characteristics of wax during solidification are measured by monitoring the radial and axial temperature profiles within the container, the effect of using finned heat exchange pipes is also examined. In an attempt to gain extra heat storage, a sensible heat material consisted of an open-ended wire mesh cylinder made out of steel is embedded in the sample, this enabled to find its effect on the speed of solidification of wax. Experimental results are presented to show the variation of solidification speed along radial sections. Comparison with theoretical predictions derived from freezing model of ice is given. The results of this research also show the advantages of finned heat transfer pipes.

Key words: Solar energy applications, phase change materials, paraffin wax, latent heat, sensible heat, results, pipes

INTRODUCTION

Renewable energy supplies are steadily gaining increasing importance in all the countries. In particular, solar energy, being non-polluting, clean and inexhaustible has received wide attention among scientists and engineers. Though there are many advantages an important factor is that solar energy is time dependent energy source with an intermittent character. Hence, some form of Thermal Energy Storage (TES) is necessary for the most effective utilization of this energy source. Most of the TES systems in use rely on the specific heat or sensible heat of the storage material such as water, soil and rock beds and they are known as Sensible Heat Storage (SHS) systems. The main disadvantage of SHS systems is low heat storage capacity per unit volume of the storage medium (Saleh and Salman, 1992). On the other hand, Latent Heat Storage (LHS) concept which involves storing and recovering heat through the solid-liquid phase change process has advantages of high heat storage capacity and isothermal behavior during charging (heat storage) and discharging (heat release) processes. Though the LHS systems have desirable characteristics, they are not in commercial use as much as SHS systems because of the poor heat transfer rate during heat storage and recovery process (Saleh and Salman, 1992; Regin *et al*., 2006; Gowtham *et al*., 2011). The main reason is that during phase change, the solid-liquid interface moves away from the convective heat transfer surface (during charging in cool storage process and discharging in hot storage process) due to which the thermal resistance of the growing layer of solidified PCM increases, resulting in poor heat transfer rate. The combined sensible and latent heat storage system eliminates the difficulties experienced in the SHS and LHS systems to a certain extend and posses the advantages of both the systems (Gowtham *et al*., 2011; Demirbas, 2006; Regin *et al*., 2009; Khudhair and Farid, 2004).

Interest in solar energy has developed during the last decade as a result of increasing costs of energy from conventional resources and due to the problems of environmental pollution. Solar energy is not utilized although, it is plentiful and available throughout the year. At present, research is going on and geared in the direction of making full use of solar energy. The intention is to utilize this source of energy in certain applications such as domestic and agricultural applications. Solar thermal applications require some means of thermal energy storage to permit system operation even in momentary interruptions of insulation and during night

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hours, the energy may be absorbed and stored by means of physical or chemical processes. The latter usually consist of reversible high enthalpy chemical reactions. The former may be classified into two main groups: these which store sensible heat by means of temperature increase and others which store latent heat of constant temperature by means of a phase change. At present formidable problems concerning mainly the non-total reversibility of the processes limit the practical extensive application of the chemical systems on the other hand usually the physical processes are totally reversible but involve less energy per unit weight of device than chemical reactions. From this point of view latent heat storage systems have the advantages of compactness in comparison with sensible heat systems because the heat of transition of most materials is very much larger than their specific heat apart from operational (advantage of the nearly constant storage temperature). Thus latent heat storage suitable for solar thermal energy storage is quite suitable for solar thermal energy storage. There are several relations between system operating conditions and storage material characteristics. For instance, the operation temperature required for the system must fit the temperature of fusion of the storage material, the temperature of fusion is one of the most important storage material properties as well as the latent heat a further consideration with phase-change materials lies in the possibility of super cooling on energy recovery if the material supercool. The latent heat of fusion may not be recovered or it may be recovered at a temperature significantly below the melting point. Identified over 50 substances as promising latent heat storage materials these cover a freezing point rang of 10-90°C of this group about 30 substances have been found to resist super cooling, paraffin waxes one of these substances listed as promising material for latent heat storage. Paraffin wax has a melting point within the range of 46-65°C shows little or no super cooling and requires no seeding, paraffin wax has other desirable properties perfect reversibility of the transition, nontoxic, chemically stable, non corrosive, cheap and available for bulk. Storage paraffin wax is perhaps the best material than others (Saleh and Salman, 1992; Demirbas, 2006; Regin *et al*., 2009). The selection of the heat storage material as a PCM in the latent heat thermal energy storage LHTES method plays an important role from the points of view of thermal efficiency (Regin *et al*., 2009; Denton and Afgan, 1976). Solar energy applications require an efficient thermal storage. The latent heat of melting is the large quantity of energy that needs to be absorbed or released when a material changes phase from a solid state to a liquid state or vice versa (Sari *et al*., 2004). The present research deals with the study of combined sensible and latent heat storage system on heat transfer in a storage unit using paraffin wax as phase change material for solar thermal applications.

MATERIALS AND METHODS

Phase change materials: Materials to be used for phase change thermal energy storage must have a large latent heat and high thermal conductivity. Depending on the applications, the PCMs should first be selected based on their melting temperature. Materials that melt below 15°C are used for storing coolness in air conditioning applications while materials that melt above 90°C are used for absorption refrigeration. Materials that melt between 15-90°C can be applied in solar heating and for heat load leveling applications (Farid and Husian, 1990). These materials represent the class of materials that has been studied most. Commercial paraffin waxes are cheap with moderate thermal storage densities and a wide range of melting temperatures. The latent heat storage medium is paraffin wax grade a supplied by Al Dora refinery (Baghdad) (Keumnam and Choi, 2000). Its melting point and thermal stability have been examined elsewhere and its principal properties are listed in Table 1.

Experimental equipment and procedure: The laboratory apparatus for this research consists of a vertical cylindrical heat storage container made of copper with an inside diameter of 83 mm wall thickness of 2 mm and length of 200 mm. A copper tube (outside diameter =12.6 mm and wall thickness =1 mm) positioned centrally along the axis of the container acts as a heat exchanger a tube length of 1200 mm is used to ensure fully developed flow of coolant fluid and to minimize end effects own stream the temperature distribution in the heat storage medium is recorded for 4 radial sections of the container using sheathed copper-consisting thermocouples connected to a multi-channel recorder (Type TR -2721 Tekada Riken Co., Japan) a total of 20 thermocouples are set up in the test unit so that each radial plane is monitored by 5 thermocouples mounted symmetrically along five radial directions and their distances from the container wall are d = 36, 30, 24, 18 and 12 mm. Two additional thermo couples are used for measuring the inlet and outlet temperature of coolant fluid passing through the heat exchanger tube. Melting of the heat storage medium is affected by a resistance heating coil through the external wall of the container this consists of a 2340 mm long resistance wire capable of generating (500 W) of heating power. A variable resistance is used to regulate the amount of power required for melting to prevent heat losses the entire unit is well insulated with layers, of glass wool. Cooling water is supplied to the unit in controllable

Table 1: Thermal properties of paraffin wax supplied by Al Dora Refinery, Baghdad

Melting point (°C)	Specific heat kJ/kg (°C)	Latent heat (kJ/kg)	Density (kg/m^3)	Thermal cond. W/m (°C)
63	3.5	173.6	780	0.17

quantities by a system of constant level tank, centrifugal pump a by-pass, regulating valves and a rot meter. The experiments were made during discharging only. The test unit was first heated up to about 5°C above the melting temperature. the maximum height of the heat-storage medium when melted was 190 mm, after allowing 20 min, melted wax to the uniform temperature, the heater was shut off and subsequently cooling water was made to flow inside the heat-exchange tube at constant flow rate which was regulated to 100, 400 and 700 L/h. for each run by a regulating valve, during each run, the temperatures of the thermocouples were measured by the digital record every 10 min.

RESULTS AND DISCUSSION

The solidification process: The experimental results from studies of the solidification of paraffin wax are illustrated. they show temperature history of the storage material at several points for each of the radial section examined. It can be seen that a radial temperature gradient does appear in a liquid state due to natural convection, however, once solidification starts, the temperature near the heat transfer surface (at d = 36 mm) quickly drops resulting in a large temperature gradient. Theoretically the temperature must go down radial as wax freezes with time, however it is noticed that the region in the vicinity of the container all (at d = 12 and 18 mm) cools at a faster rate than that in the interior of the storage unit these observations indicate that the unit is losing heat through the external surface despite the action. Heat through thermal insulation has been requirement is considered loses through thermal insulation have been reported by various researchers. The effect seems to be unavoidable with practice systems and in fact insulation requirement is considered as one of the disadvantages associated with latent heat storage systems.

The radial temperature gradient is considered to be determined from a balance of heat transferred to cooling water and heat conducting in the storage material. The dominating heat resistance is that of the solid phase and thus increases with the latter s thickness. Therefore, the cause of the observed temperature drop must be low thermal conductivity of solid wax. Although, axial temperature profiles are not shown here, the axial temperature gradient was noticed to be smaller than the radial temperature gradient, however, axial temperature profiles next to container wall also revealed the effect of heat losses through insulation.

Freezing time as faction of radial distance: Freezing time of wax in the direction of increasing radius for the tested cross sections the results were obtained by noting. The time at which a phase change occurs and from knowledge of positions of thermocouples, the corresponding freezing radial was estimated. It is seen that at the bottom of the container, freezing occurs almost simultaneously at all points apart from areas next to the water tube which show a faster rate of solidification further up the plots assume a bell-shaped profile with a clear maximum existing at a mid- point between the tube and the container wall. The maximum is much more apparent at the top of the unit, the observed variations in local speed of solidification along radial planes suggests that the core of solidified wax was evolving into a conical shape rather than cylindrical. This has been reported before (Anonymous, 1981; Selvidge and Mioulls, 1990). However, in the present research some visual observations were attempted to confirm the existence of such cone.

Total heat released during phase change: At the onset of solidification, a freezing front emanating at the tube surface interludes the phase change material until some finite time where it is completely solidified. The layer of solidified material offers a resistance to heat transfer which is a function of time. The amount of heat released to coolant fluid when the phase boundary moves a radial distance R_n is given by Eq. 1 and 2:

$$Q_n = Q_1+Q_2 \quad (1)$$

or

$$Q_n = M_n (\lambda + C_p \Delta T) \quad (2)$$

Q_1 = Heat released due to phase change (kJ)
Q_2 = Heat released due to sensible heat of phase change material (kJ)
M_n = Mass of solidified core which is a function of R_n (kg)
λ = Latent heat of fusion of phase change material, (173.6 kJ/kg for paraffin wax)
C_p = Specific heat (3.5 kJ/kg for wax)
ΔT = Difference between melting and final steady state temperance of solidified mass, i.e., ΔT = 65-25 = 40°C

Where:

Q_n = A function of M_n only
M_n = A function of R_n on increases from zero at the onset of solidification

Table 2: Latent and sensible heat for different systems in this research

System		Phase change only			
R_n (mm)	M_n (kg)	Q_n (kJ)	With wire mesh	Tube with 7 fins	Tube with 14 fins
8.2	014.5	004.6	005.3	005.2	005.8
14.5	076.0	024.1	024.9	024.8	025.4
20.5	171.0	053.9	054.7	054.6	055.2
26.5	299.5	093.9	094.1	094.5	095.2
32.5	459.6	144.1	144.9	144.7	145.4
38.5	650.0	203.8	204.9	204.5	205.1
41.4	755.0	263.0	234.3	233.3	236.8

where, $R_n = R_o$ (the outside radius of inner tube) to a full value at the end of the solidification process where $R_n = R_i$ (the inside radius of the heat storage container). If heat losses through insulation is ignored Eq. 2 provides the theoretical amount of heat that can be stored and subsequently released in an ideal systems.

Heat release In the presence of sensible heat storage materials: Two types release heat materials were investigated: For the purpose of increasing heat removal, annular fins (0.22 mm thickness and 61.5 mm in diameter) cut from copper sheets were attached circumferentially, equally spaced to the heat transfer tube. In this set up, the effect of using 7 or 14 fins was investigated.

For the purpose of increasing heat storage capacity, an open-ended wire mesh cylinder (52 mm in diameter and 180 mm in length) made out of steel was placed concentrically. The amount of sensible heat stored by these materials which is subsequently released to coolant fluid is given by:

$$Q_3 = M_s C_{ps} T \tag{3}$$

Where:

M_s = Mass of sensible heat material (kg)
C_{ps} = Specific heat (kJ/kg°C)

Introducing Q_3 into Eq. 3, the total heat released during phase change in the presence of a sensible heat storage material is:

$$Q_n = M_n (\lambda + C_p \Delta T) + MsC_{ps} \Delta T \tag{4}$$

Results derived from Eq. 4 are tabulated in the Table 2 reflects the results of Eq. 2 and 3 for the systems involved in this research. As can be seen Q_n varies nonlinearity with radial position but with negligible difference between each system. In other words, the presence of sensible heat materials (fins and wire mesh) makes only a minor contribution to the total heat gain. The reason is that their thermal capacitance ($M_s C_{ps}$) is small in comparison with the phase change material, however, the heat storage capacity can be significantly increased if the mass of added heat sensible material is increased. For example, in one recent application (Selvidge and Mioulls, 1990; Gross and pesotchinsk, 1981), a massive metal honeycombs were used for extra heat storage on the other hand, the rate of heat release is found to be different for each system. As will be seen later with finned systems the rate of heat flow is much higher than those without fins.

Rate of heat release: The rate of heat release is much higher at the bottom of the container than at the top, it indicates that the storage material releases its heat most quickly at the base where cooling water gets warmer is introduced to the storage unit. As cooling water gets warmer through upper sections, the heat transfer rate drops due to reduced temperature difference between melt and coolant. Consequently, the difference in the rate of heat release between the lower and upper sections of the container leads to the initial development of conical shape of solidified material (Bailly, 1975).

The results obtained for the middle section of the container in the presence of sensible heat materials. It is evident that fins have pronounced effecting the rate of heat release and speed of solidification. A finned tube offers a larger heat exchange capacity than a bare tube and consequently higher rate of heat flow and shorter time for complete solidification are obtained with a finned system. Contrary to fins, the use of an open-ended wire mesh cylinder for extra storage leads to adverse effect, it suppressed the rate of heat flow and increased the time for complete solidification. The wire mesh is apparently acting as a time log element, probably due to lack of thermal bonding with the heat transfer tube. This time lag is generated due to thermal capacitance of wire mesh and its resistance to heat transfer practical result is to make the response of the and the process slower than that without wire mesh.

Another sample of the experimental results is the effect of coolant flow rate of heat release. It can be seen that the rate of heat flow increases with coolant flow rate, the increase is much more apparent with finned tube system as water flow rate Increases from 100-700 L/h. these results also reflect the advantages of using finned tubes for heat exchange in a solar storage unit.

CONCLUSION

Heat release characteristics in a latent heat storage unit for solar thermal application utilizing commercial paraffin wax have been investigated experimentally and the following are concluded: Temperature histories of the storage material recorded at different positions reveal the existence of radial and axial temperature gradients. The axial temperature gradient is found to be smaller than radial temperature gradient. The temperature of the heat exchange surface quickly drops soon after the commencement of solidification due to lower thermal conductivity of the storage material, thus, resulting in a large temperature gradient near the tube surface.

The effect of heat losses through insulation has been recognized, its effect seems to be unavoidable with practical units.

Due to variation of local speed of solidification between radial sections the solidified core initially assumes a conical shape growing with time and them eventually fills the container.

An attempt has been made to predict freezing rates of wax based on freezing model of ice. Theory and experiments show some correspondence to each other but the deviation quite apparent. Qualitative explanation for the deviation given.

For the systems investigated in this research, heat transfer pipes equipped with fins are found to be very effective for heat transfer and speed of solidification contrary to fins, the use of cylindrical wire mesh embedded concentrically within the concentrically within the storage material leads to adverse effects lowering speed of solidification and reducing rate of heat release.

REFERENCES

Anonymous, 1981. Marketing specification of Iraqi oil production ministry research of oil. State Organization for Marketing of Oil, Baghdad, Iraq.

Bailly, J.A., 1975. Research on solar energy storage subsystem utilizing the latent heat of phase change of paraffin hydrocarbons for the heating and cooling of building. U.S. Department of Commerce, Washington, USA.

Demirbas, M.F., 2016. Thermal energy storage and phase change materials: An overview. Energy Sour. Part B. Econ. Plann. Policy, 1: 85-95.

Denton, J.C. and J. Afgan, 1976. Future Energy Production Systems: Heat and Mass Transfer Processes. Vol. 1, Academic Press, New York, ISBN:9780122100017, Pages: 866.

Farid, M.M. and R.M. Husian, 1990. An electrical storage heater using the phase-change method of heat storage. Energy Convers. Manage., 30: 219-230.

Gowtham, M., M.S. Chander, K.S.S. Mallikarujanan and N. Karthikeyan, 2011. Concentrated parabolic solar distiller with latent heat storage capacity. Intl. J. Chem. Eng. Appl.,2 2: 185-188.

Keumnam, C. and S.H. Choi, 2000. Thermal characteristics of paraffin in a spherical capsule during freezing and melting process. Intl. J. Heat Mass Transfer, 43: 3183-3196.

Khudhair, A.M. and M.M. Farid, 2004. A review on energy conservation in building applications with thermal energy storage by latent heat using phase change materials. Energy Conversion Manage., 45: 263-275.

Regin, A.F., S.C. Solanki and J.S. Saini, 2006. Latent heat thermal energy storage using cylindrical capsule: Numerical and experimental investigations. Renewable Energy, 31: 2025-2041.

Regin, A.F., S.C. Solanki and J.S. Saini, 2009. An analysis of a packed bed latent heat thermal energy storage system using PCM capsules: Numerical investigation. Renewable Energy, 34: 1765-1773.

Saleh, W.M. and J.M. Salman, 1992. Release of latent and sensible heat of paraffin wax for solar energy applications. Proceedings of the International Conference on Renewable Energy, June 22-26, 1992, UNESCO, Amman, Jordan, pp: 549-560.

Sari, A., H. Sari and A. Onal, 2004. Thermal properties and thermal reliability of eutectic mixtures of some fatty acids as latent heat storage materials. Energy Convers. Manage., 45: 365-376.

Selvidge, M. and I.N. Miaoulis, 1990. Evaluation of reversible hydration reactions for use in thermal energy storage. Sol. Energy, 44: 173-178.