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STUDY OF HEAT TRANSFER IN CO- GENERATION ENERGY STORAGE SYSTEM IN BUILDING

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ABSTRACT

Cogeneration plants benefit from many of the energy efficiency improvements that are brought about in utility power generation because the same basic technology is employed in both cases. However, cogeneration being more attractive for small-scale decentralized applications, significant technological progress has been made in the development of modular and packaged cogeneration systems of lower capacities. Moreover, as such systems are being adopted in industrial zones and city centers, the stringent laws and regulations put in place for protecting the local environment has obliged the cogeneration technology providers to innovate incessantly. The usage of phase change materials to store the latent heat in the form of latent heat is increased, because large quantity of thermal energy is stored in smaller volumes. A thermal storage device is composed of an inner aluminum sheet having a wide of 30 mm and length of 1000 mm. The sheet passes through a rectangular storage device have a wide 600 mm, fill with paraffin wax. In the present work the numerical study of the effects of convection, fins and the method of heating surface constant wall heat flux , changing heated surface temperature and heat flux on the storage characteristics of latent heat energy storage system (LHESS) using the CFD software FLUENT6.3.26. The results show that the effect of convection cannot be neglected, but it is decreased when the space of liquid to moving decreased that occurs when increased numbers of fins, in the case of constant wall temperature the heat transfer increase when the number fins increase and found that after 12 hours the rate of energy stored increased to 116.5% and 89.6% and 89.6% at 3 fins, 8 fins and 13 fins respectively. The effect of fins is small for a constant wall heat flux, no fins is the beast case for storage energy, simple design and less cost than with fins.

NOMENCLATURE

Cp	Specific heat capacity (J kg^{-1} K^{-1})
E	Total energy stored (J)
K	Thermal conductivity (W m^{-1} K^{-1})
L	Latent heat of fusion (J kg^{-1})
T	Temperature (K)
S	Source term
t	Time (s)
V	Velocity vector
h	Sensible enthalpy
H	Total enthalpy
g	Gravity

Greek symbols

ρ	Density kg m^{-3}
λ	Liquid fraction
B	volumetric expansion coefficient
ν	Dynamic viscosity

Abbreviations

CFD	Computational fluid dynamic

LHESS	Latent heat energy storage system
SHSS	Sensible heat energy storage system
PCM	Phase change material
TESS	energy storage system
ESCO	energy service company
IC	Internal combustion

INTRODUCTION

Cogeneration is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy may be used either to drive an alternator for producing electricity, or rotating equipment such as motor, compressor, pump or fan for delivering services. In a gas turbine or reciprocating engine, typically a third of the primary fuel supplied is converted into power while the rest is discharged as waste heat at a relatively high temperature, ranging between 300 and 500°C. At sites having a need for thermal energy in one form or the other, this waste heat can be recovered to match the quantity and level of requirements. For instance, steam may be needed at low or medium pressures for process applications. Any heat recovered from the exhaust gases of the prime movers will help to save the primary energy that would have been otherwise required by the on-site conversion facility such as boilers or dryers.Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling.Thermal energy storage (TES) system using phase change materials (PCM) as a storage medium offers advantages such as high heat storage capacity, small unit size and isothermal behavior during charging and discharging when compared to other sensible heat storage (SHS) system. TES has various domestic, industrial and power generation applications and it is useful way of decreasing costs and overall electricity demand. Better power generation and economic benefit can be achieved if some of peak load could be shifted to the off peak load period , which can be achieved by thermal storage of heat or coolness so the size of air handling unit in air conditioning systems would be smaller (Khudhair *et al.* 2004). As a result, this technology is becoming more applicable to a wide range of heating, ventilation and air–conditioning systems and (Halford *et al.* 2007). TESS applications include passive storage in building, thermal protection of food and electronic devices, solar energy thermal storage and heating water (Sharma *et al.,* 2009). According to (Ogoh 2010) it is obvious that any energy storage systems incorporating phase change materials will comprise significantly smaller volumes when compared to other materials storage only sensible heat. Thermal efficiency of IC engines becomes low due to huge percent of the engine heat loses mostly through the radiator and the exhaust pipe, and partly through engine walls during the engine operation. Furthermore, sunlight is also another source of heat for vehicles in summer, by means of applying an efficient TES application. The waste heat is taken from the coolant and exhaust pipe of the engine. The stored energy can then be discharged in cold weather starting to preheat the engine, preheat the catalytic converter and/or heat-cool. in the industry, PCM are used in cooling of engines, thermal comfort in vehicles, pre heating of engine (Schatz 1992; Vasiliev, Burak *et al.* 1999; Vasiliev, Burak *et al.* 2000; Gumus 2009), pre heating of evaporator and pressure regulator of gaseous sequential injection system (Gumus *et al.,* 2011) and other application in internal combustion engines (Boam 1986). Co generation technologies enable the simultaneous generation of heat and electricity, increasing the overall energy efficiency of the conversion process in comparison with conventional thermal generation technologies. This efficiency is achieved by partially recovering heat produced during electricity generation to make it available for end use applications.

LITERATURE REVIEW

For more power is required at any site, it is possible to adopt a combined cycle that is a combination of gas turbine and steam turbine cogeneration. Steam generated from the exhaust gas of the gas turbine is passed through a backpressure or extraction condensing steam turbine to generate additional power. The exhaust or the extracted steam from the steam turbine provides the required thermal energy. The exhaust gas can used as a heating element of heating or cooling the housing.

In the storage systems, the modes of heat transfer encountered in the melting and solidification of phase change materials (PCM) are conduction, convection and close melting (Bejan, 1994). Melting of phase change materials in rectangular enclosures has received considerable attention. It was demonstrated numerically that free convection plays a role during the melting process encountered in rectangular geometries (Wang *et al.* 1999). It was concluded that the heat transfer rate and the melting time increased and decreased respectively, as the volume fraction of nanoparticle increased, (Lamberg *et al.,* 2004) obtained physical validation of the numerical results produced using FEMLAB. Through a comparison of experimental data and numerical results. (Zhengguo *et al.,* 2005) experimentally studied the thermal performance of paraffin/ expanded graphite composite phase change material. The heat transfer rate of the paraffin/expanded graphite composite was obviously higher than that of paraffin due to combination with the expanded graphite that had a high thermal conductivity. The numerical methods studied were an enthalpy method and an effective heat capacity method. Both numerical methods gave good estimations for the temperature distribution of the storages in both the melting and freezing processes. The melting process in spherical geometry of PCM was studied numerically by (Assis *et al.,* 2007). Also, detaled parametric investigation of melting spherical shells of various diameters with a uniform temperature. (Medrano *et al.,* 2009) experimentally investigated the heat transfer process during melting (charging) and solidification (discharge) of five small heat exchangers working as latent heat thermal storage systems. The results showed that the double pipe heat exchanger with PCM embedded in a graphite matrix was the one with higher values of storage. During the freezing process, the temperature clearly leveled out during the phase change, due to the increase in specific heat. But in the melting process, this leveling out of temperature over the phase change range could almost not be noted at all. (Ogoh, 2010) presented a numerical study of the effects of fins and thermal fluid velocities on the storage characteristics of a latent heat energy storage system. The results showed that the heat transfer rate increases with addition of fins and increases thermal fluid velocity. The effect of HTF velocity is small with few fin configurations. The total energy stored after 12 hours for 0 and 27 fins configurations range between 3.6 MJ and 39.7 MJ for thermal fluid velocity of .05 m/s and between 3.7MJ and 57 MJ for .5 m/s. The highest system efficiencies for the .05 m/s and .5 m/s ,obtained with 27 fins are 68.9% and 97.39% respectively. The heat transfer coefficient was more important than increase of heat transfer area. (Johansson, 2011) carried out an advanced heat transfer analysis for phase change thermal energy storage system by looking at the heat transfer mechanisms in a finned cylindrical PCM heat exchanger The position of the heat exchanger affected the overall heat transfer effect, this is because the vertically placed fins inhibit the convections less as there is larger space for gravity assisted convection mechanism During the freezing process, the temperature clearly levels out during the phase change, due to the increase in specific heat . But in the melting process, this leveling out of temperature over the phase change range can almost not be noted at all. (Sebti *et al.,* 2011) has studied heat transfer enhancement during melting in a two-dimensional cylindrical annulus through dispersion of Nano particle is investigated numerically. Paraffin–based Nano fluid containing various volume fractions of Cu is applied. It is found that the suspended Nano particles give rise to the thermal conductivity as compared to the pure fluid and consequently the heat transfer is enhanced. In addition, the heat transfer rate and the melting time increase and decreases respectively, as the volume fraction of nanoparticle increases," (Reddy *et al.,* 2012) studied the heat transfer in PCM. The variable studied included PCM, mass flow rate, and inlet temperature of heating transfer fluid. The PCM were stored in the form of spherical capsules of 38 mm diameter made of high density poly ethylene. It was concluded that the charging time can be reduced with increasing mass flow rates of heat transfer fluid. Stearic acid attains maximum temperature (equal to heat transfer fluid inlet temperature) faster compared to paraffin. Also, it is stated that, from economic point of view, the stearic acid is recommended as PCM for TESS.

Most of the previous work in literature not take into account natural convection and heating with constant heat flux so, in the current work, the heat transfer in PCM storage tank is numerically investigated using FLUENT 6.3.26. The numerical results are validated through a comparison with results from literature studied. Then, the effect of convection, number of fins and heating surface temperature on the PCM in cylindrical tank is numerically investigated. In numerical model with constant heat flux to check the numerical model is correct for solving heat flux boundary condition. Then , the effect of convection, number of fins on the PCM inside tank is numerically investigated on practical design for storage.

MATHEMATICAL MODEL

A cylindrical thermal storage device is studied as shown in (Fig 1) it is composed of an inner aluminum pipe having inner/outer diameter of 20/30 mm and length of 1000 mm. The pipe passes through a rectangular shape storage with a wide of 600 mm, filled with paraffin wax which is used because of its high storage capacity and low melting temperature, In addition to its thermo physical properties presented in (Table 1). To increase the rate of heat transfer from the pipe surface to paraffin wax aluminum fins are added to the pipe with 5 mm thickness. (Groulx and Ogoh, 2009).

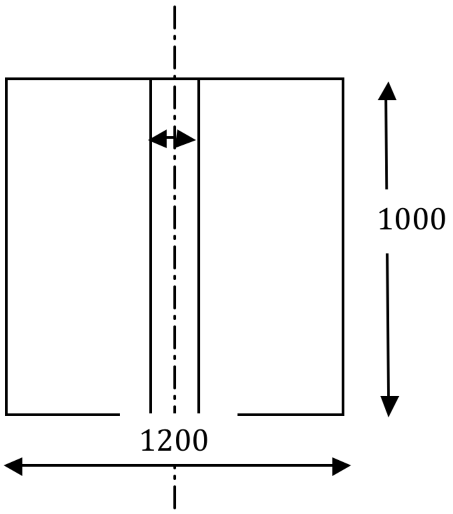


Fig. (1) : Geometry of thermal storage device.

Table (1) : Thermo physical properties of Paraffin Wax Materials (Groulx and Ogoh 2009).

Thermal conductivity	.21 W/m.k
Heat capacity	2.5 kj/kg.k
Density	900 kg/m3
Enthalpy of fusion	174 kj/kg
Temperature range melting	313 K to 316 K

(Hosseini *et al.,* 2012). In order to simulate phase change in a shell and tube heat exchanger, enthalpy method is used. The continuity, momentum, and thermal energy equations can be expressed as follows:

Continuity:

$$\nabla.\vec{V} = 0$$

Momentum:

$$\frac{\partial\vec{V}}{\partial t} + \vec{V}.\nabla\vec{V} = \frac{1}{\rho}\left(-\nabla P + \mu\nabla^2\vec{V} + \rho\beta\,\vec{g}\left(T - T_{ref}\right)\right) + \vec{S}$$

Thermal energy:

$$\frac{\partial h}{\partial t} + \frac{\partial H}{\partial t} + \nabla.\left(\vec{V}h\right) = \nabla.\left(\frac{k}{\rho\, C_p}\nabla h\right)$$

The enthalpy of the material is computed as the sum of the sensible enthalpy, h, and latent heat, ΔH:

$$H = h + \Delta H$$

The latent heat content can be written in terms of the latent heat of the material, L :

$$\Delta H = \lambda * L$$

Where ΔH may vary from zero (solid) to L (liquid), therefore, the liquid fraction, λ can be defined as:

$$\lambda = \begin{cases} \frac{\Delta H}{L} = 0 & \text{for } T < T_{solid} \\ \frac{\Delta H}{L} = 1 & \text{for } T < T_{liquid} \\ \frac{\Delta H}{L} = \frac{T - T_{solid}}{T_{liquid} - T_{solid}} & \text{for } T_{solid} < T < T_{liquid} \end{cases}$$

Darcy's law damping terms (as source term) that are added to the $\vec{S}$ momentum equation due to phase change effect on convection, it is defined as:

$$\vec{S} = \frac{(1-\lambda)^2}{\lambda^3} A_{mush} \vec{V}$$

The coefficient is a mushy zone constant; this constant is large number, In present study is assumed constant and set to 10^6.

Numerical solution is carried out using the CFD software FLUENT6.3.26 to solve melting modeling and energy equation in three steps. Firstly, the geometry is created with GAMBIT software and consists of two parts. Fins and heated tube is treated as solid and spacing between fins is treated as fluid (PCM). Secondly, mesh is created by discretizing the computational domain into different mesh elements to maintain minimum skewness. The convergence criterion of 10^{-6} is used for the studied case. The boundary conditions are as follows the outer casing is insulated and the pipe is heated under constant wall temperature. Thirdly, the physical parameters for 2-Dimension axisymmetric model (PCM) used in this study , the specific heat capacity of paraffin wax has the following form) Salyer and Sircar .1986).

$$cp = \begin{cases} 2.5 \frac{kj}{kg} \text{ for } T < 313\ K \\ 60.5 \frac{kj}{kg} \text{ for } 313K > T < 316K \\ 2.5 \frac{kj}{kg} \text{ for } T > 316\ K \end{cases}$$

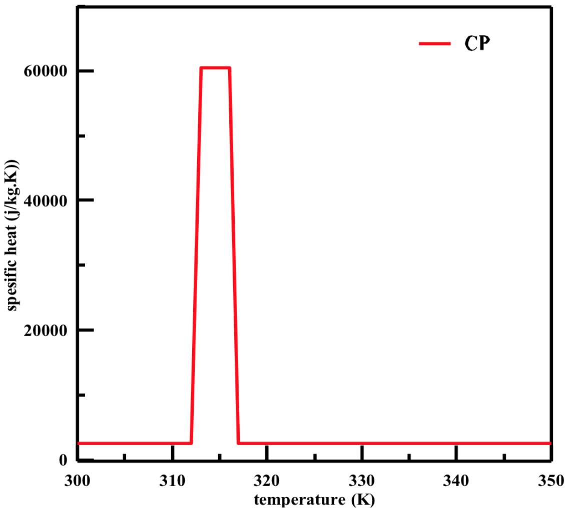


Fig. (2) : variation specific heat with temperature

The stored energy is in two forms sensible and latent heat. Sensible heat plays a major role in regions where the temperature of PCM is below 313 K or above 316 K and between these two temperatures the latent heat is dominated.

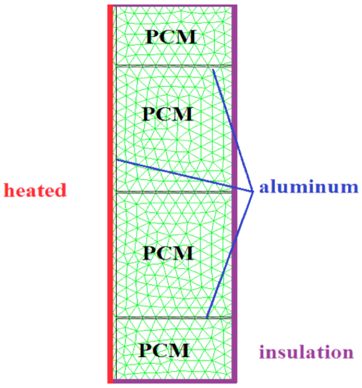


Fig. (3) : Numerical modeling and meshing of studied geometry (3 fins).

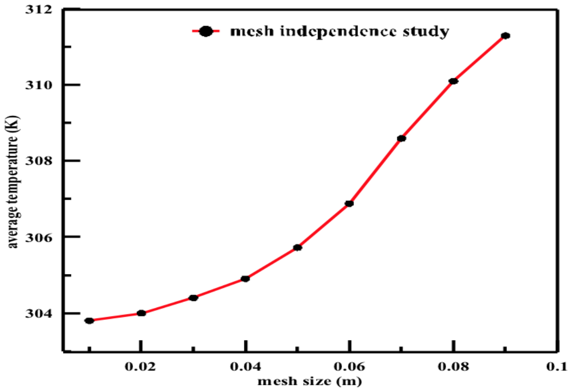


Fig. (4) : dependence of mesh size.

MODEL VALIDATION

A study on mesh size was made in FLUENT 6.3.26 to determine the optimum mesh size to use without losing much accuracy. The results shown in Fig (4) are for mesh sizes of (.01, .02 , .03, .04, .05, .06 and .07m); it is seen from the figure that the volume size below .03m did not change largely the PCM average temperature.

The PCM average temperature are compared with published results of (Groulx and Ogoh 2009). As shown in Fig (5) and Fig (6) for no fins and 3 fins respectively. It can be seen from the figures that the present result is close to the results of published one.

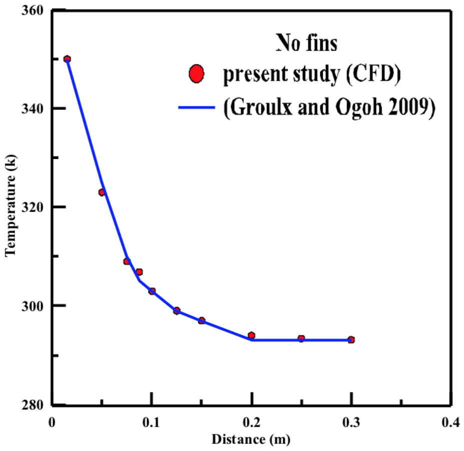


Figure (5): comparison between Groulx and case study for no fins.

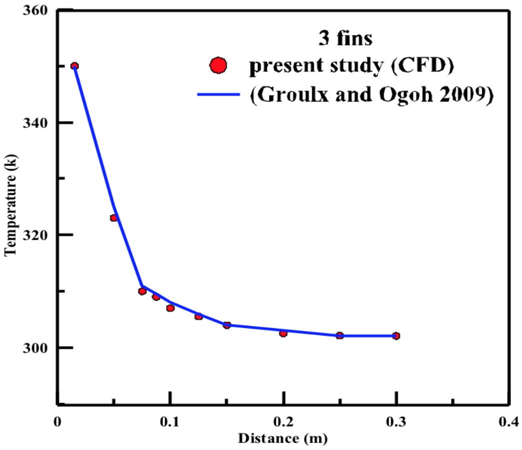


Figure (6): comparison between Groulx and case study for (3)fins

RESULTS AND DISCUSSION

Figure (7) Present the temperature distribution inside the PCM after 12 hours for conduction model at constant heat flux with no fin and (3, 8, 13) fins. As can be seen from this figure, the number of fins plays an important role on the overall charging and melting process. Fig (8) Present the relation between average temperature and time of charging. It is seen from the figure that the average temperature of PCM increases with number of fins, because the fins increased the surface area and consequently increases the heat transfer to PCM (Fig. 9 & 10) .

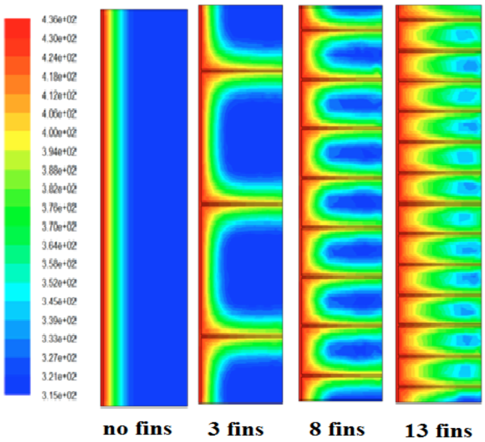


Fig. (7) : Temperature distribution obtained after 12 hours of charging at constant heat flux.

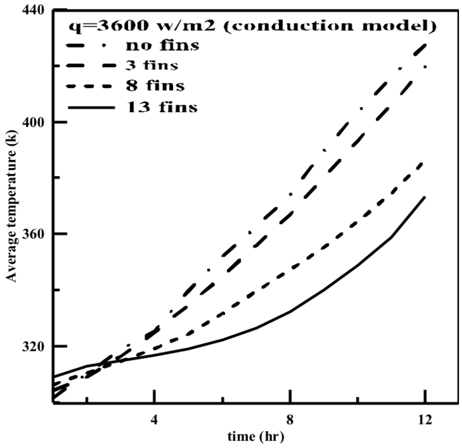


Fig. (8) : show the average temperature for the PCM at constant heat flux for various numbers of fins

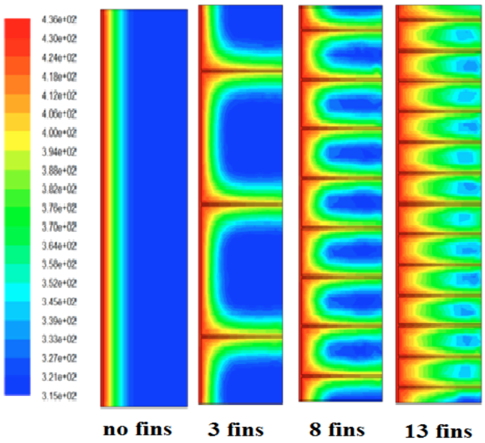


Fig. (9) : liquid fraction distribution obtained after 12 hours of charging.

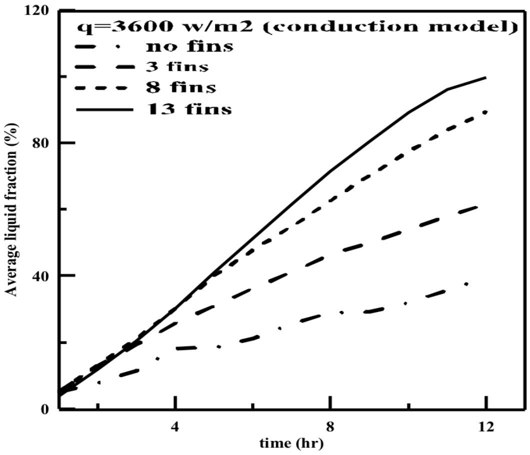
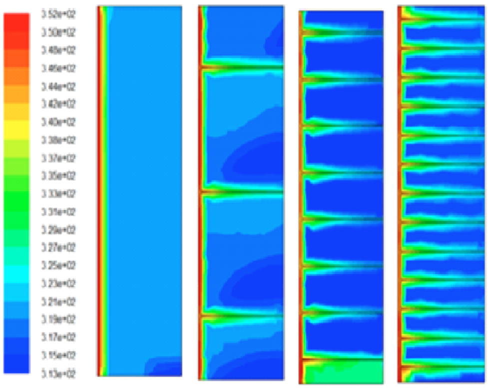


Fig. (10) : show the liquid fraction in the PCM for various numbers of fins.

conduction-convection model:

Figure (11) present the temperature distribution inside the cylindrical PCM after 8 hours of no fins and (3, 8, 13) fins. Shown from this figure, the number of fins and the convection effect plays an important role in increasing the overall charging and melting process than conduction only.



no fins 11 hours · 3 fins 9 hours · 8 fins 9 hours · 13 fins 8 hours

Fig. (11) : Temperature distribution obtained for storage unit at charging.

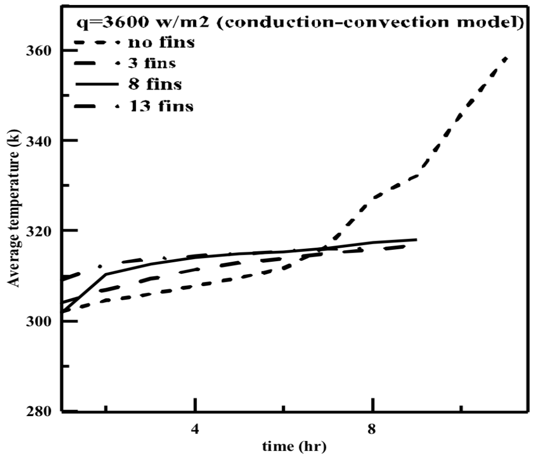
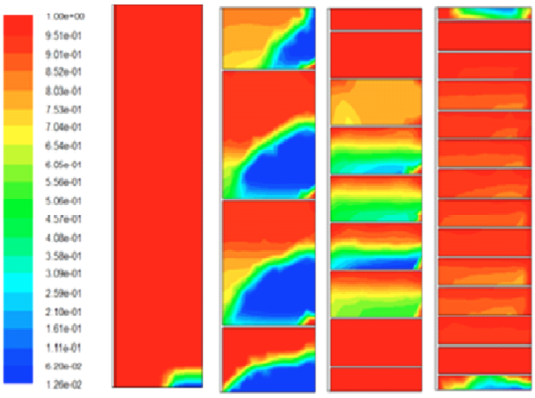


Fig. (12) : PCM average temperature versus with time at various numbers of fins.

Fig (12) presents the relation between average temperature and time of charging. It is seen from the figure that the average temperature of PCM increases with number of fins and less than that of conduction only. This is may be because most of energy is used to change the phase of PCM. Fig (13) present the liquid fraction distribution inside the cylindrical PCM after 8 hours of no fins and (3, 8, 13) fins.



no fins 11 hours · 3 fins 9 hours · 8 fins 9 hours · 13 fins 8 hours

Fig. (13) : liquid fraction obtained for storage unit at charging.

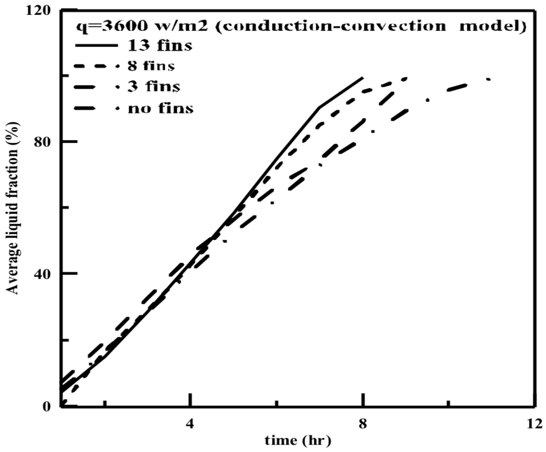


Fig. (14) : The liquid fraction in the PCM versus time for various numbers of fins.

Fig (14) presents the relation between average liquid fraction and time. It is seen from the figure that the average liquid fraction of PCM increases with number of fins until reach to a maximum value of (99%) after 7 hours for the 13 fins and (99.7%) after 10 hours for the 8 fins.

comparisons between the results of the two models.

Fig (15) presents the relation between percentage increased in average liquid fraction between the convection-conduction model and the conduction model only, and time. It is seen from the figure that the percentage increased in average liquid fraction of PCM decreases with increases of number of fins this is because increasing number of fins reduces convection effect due to the reduction of space of PCM thickness.

Fig (16) presents the relation between percentage increases in total energy stored in PCM and time. It is seen from the figure that the percentage increased in total energy of PCM decreases when increases number of fins because increasing fins reduced convection effect by reducing space of PCM.

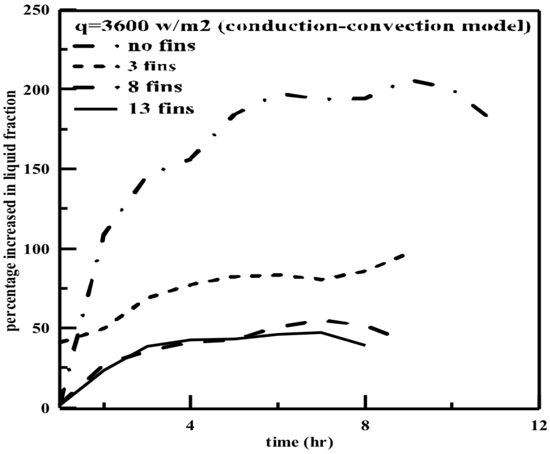


Fig. (15) : The relation between the percentage increased in average liquid fraction and time at various numbers of fins.

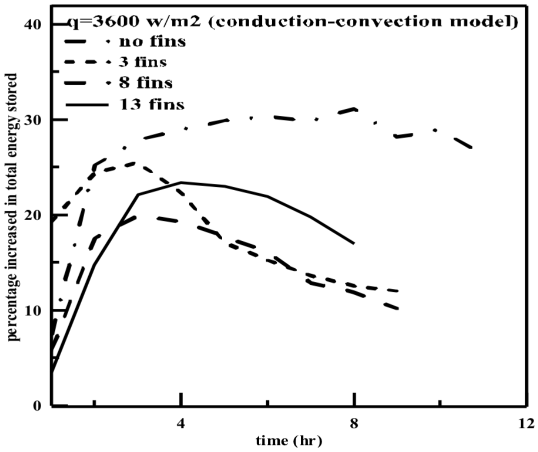


Fig. (16) : The relation between the percentage increased in total energy stored and time at various numbers of fins.

CONCLUSION

1- Free convection plays a role during the melting process inside storage system and must not be neglected.
2- Liquid fraction and total energy stored in PCM increases with time for both conduction and conduction-convection models.
3- The effect of fins is nearly to be neglected when heating by constant wall heat flux, no fins is the best case for storage energy, simple design and less cost than with fins.
4- Time of melting of PCM decreases with increases number of fins for both models.
5- Time of melting, liquid fraction and total energy stored enhances using conduc-

tion-convection model.

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الملخص العربى

إدارة الطاقة المستخدمة في الأبنية الجديدة باستخدام التوليد المشترك للطاقة

محمد جمال واصل **محمد غصوب سعفان**
شيماء نبيل هجرس
قسم هندسة القوى الميكانيكية - كلية الهندسة - جامعة المنصورة

التوليد المشترك للطاقة يكون أكثر جاذبية للتطبيقات اللامركزية على نطاق صغير، وأحرز التقدم التكنولوجي الكبير في تطوير نظم التوليد المشترك للطاقة وحدات مختلفة من قدرات أقل. وعلاوة على ذلك، كما يتم تبني مثل هذه النظم في مناطق ومراكز المدن الصناعية والقوانين واللوائح الصارمة التي وضعت لحماية البيئة المحلية وملزمة لمقدمي التكنولوجيا التوليد المشترك للطاقة على الابتكار باستمرار. استخدام المواد فى مرحلة تخزين الطاقة مثل المواد متغيرة الطور والتى لها حرارة كامنة كبيرة وتخزن الطاقة في شكل حرارة كامنة ، لأنه يتم تخزين كمية كبيرة من الطاقة الحرارية في حجم أصغر. ويتألف جهاز التخزين الحراري متوازى مستطيلات من الألومنيوم يوضع بداخل متوازى مستطيلات أبعاده الداخلية بوجود مجموعة من العوارض من 30 مم وطول 1000مم. يمر عبر جهاز تخزين متوازى مستطيلات عرض 1200 مم، ومليء بشمع البرافين . وتم عمل دراسة عددية وذلك لحساب مدى تخزين الطاقة مع وجود حمل حر وزعانف ومع فيض حرارى ثابت وتم دراسة سطح تدفق الحرارة، وتغيير درجة حرارة السطح الساخن مع تدفق الحرارة على خصائص تخزين الحرارة كامنة نظام تخزين الطاقة الحرارية (LHESS) باستخدام برنامج .FLUENT6 CFD .3.26 وأظهرت النتائج انه بزيادة عدد الزعانف يزيد معدل انتقال الحرارة وتقليل زمن انصهار الشمع وبمقارنة النتائج بالنتائج السابقة وجد توافق الى حد ما

JOESE 5

STUDY OF HEAT TRANSFER IN CO- GENERATION ENERGY STORAGE SYSTEM IN BUILDING

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