University of Thi_Qar Journal for Engineering Sciences
http://www.doi.org/10.31663/tqujes.10.2.369(2019)
Vol 10.2 (September 2019)

ISSN :2664- 5572 (online)
ISSN:2664-5564 (print)
Available at http://jeng.utq.edu.iq
utjeng@ utq.edu.iq

Using of PCM as an energy storage material to improve the cooling process in electrical transformers

Alaa Abdullah Abduladheem[†], **Mushtaq Ismael Hasan** [‡]

[†] Mechanical Engineering Department, College of Engineering, Thi-Qar University, Iraq

[‡†] Mechanical Engineering Department, College of Engineering, Thi-Qar University, Iraq

Abstract

In this investigation using (PCMs), the phase change materials in the electrical transformer is numerically analyzed by CFD. In this paper used oil transformer and PCMs (Wax, RT44 and P116), the cooling as mediums which are represented the heat storage assistance the oil. Ten kilogram of PCMs used as shield around the windings and coils. A (25, 37, 45 and 55 C^o) represented surrounding temperatures that are taken. Because of, absorbed the heat by the latent heat that got it from PCM, the PCM added at transformer temperature shows clear decreasing the average temperature. The boundary condition represented with mixed (convection and radiation), heat generation applied on the transformer. The results displayed that, temperature reduction of the transformers is about 4 C^o due to use of different types of PCM.

Keywords: transformer, electrical, cooling, CFD numerically investigation, B.C. boundary condition.

NOMENCLATURE:

Cp	Specific heat ($J.kg^{-1}.K^{-1}$)
k	Thermal Conductivity (W/m.K)
$m^{\cdot}$	Mass flow Rate ($kg.s^{-1}$)
P	total pressure (Pas.)
q	Heat transfer rate (Watt)
T	temperature (K)
u	fluid x-component Velocity ($m.s^{-1}$)
v	fluid y-component Velocity ($m.s^{-1}$)
w	fluid z-component Velocity ($m.s^{-1}$)
h	heat transfer Coefficient
ΔH	Latent heat (Watt)
H	Enthalpy of suspension (Watt)
h_e	Sensible heat (Watt)
L	Latent heat of fusion (Watt)

Greek Symbols:

ρ	density ($kg.m^{-3}$)
μ	dynamic viscosity ($m^2.s^{-1}$)
β	Melting fraction

Abbreviation

Temp.	Temperature
Paraf.	Paraffin wax
PCM	Phase Change Material
V	volume

1- Introduction:

It is so necessary to analytical Electrical transform and it is very important in the daily life;

PCM used to improve the thermal performance of transformer and used to absorb extra heat through peaks in dissipation power. The heat absorption by a phase change material generally, occur between the liquid and the solid states.

Jon G. et al. (2011) [1] studied the thermal behavior of several (ONAN) (Natural oil-Natural air) of the transformers. To properly geometric description was used to easy presented evidence model. To get a little cost that, required computational, the distribution thermal confidential the transformer. In addition, flow of oil can be study through this model. To solve model used FVM (finite volume method). The results that, the slice model of oil developed, has been accept ability supplies entire transformer to present the thermal performances. In addition, (2.4℃) which is represented the difference in the max temperature of probe oil.

Garlos M. et al. (2011) [2]. Studied the distribution of temperature and flow in the electrical transformers. In their study, experimentally studied the electrical transformers because it is not easy study. Therefore, used the CFD simulation for a solving these case. CFD simulations were accepted out to analyses the flow distribution and heat removal in a core type power transformers. The results attained presented that, CFD used has been publicized to be suitable for study and can give a highest role in improving to problematic states revision as thermal analysis of transformers. Also, it suitable designing of transformers, giving information complete on flow and distribution of temperature. When the temperature distribution excluding the amount and the location of the highest temperature in a transformer (hot spot temperature).

Srinivasan (2013) [3] (2012) from (100 MV) depending on the real details gathered, the projected model has been certified electrical transformer. This model used the semi-physical including of the environmental and surrounding variables for the find of (hot spot temperature) and effect of life the isolation in transformer. A (top-oil temperature) a function used to find of coils. That can be found by using of the wind velocity, ambient temperature, transformer data, top oil temperature saved repressor value, and effect of heat radiation from the solar.

Dong et al [4] (2013) (AlN) the transformer oil aluminum nitride based on nano-fluid which are prepared. The special effects are analyzed dependent on the composition of electrical conductivity at changed temperatures of surrounding. They found that, nonlinear electrical conductivity dependencies on temperature and the volumetric fraction. In comparison, the electrical conductivity of nano-fluid inclosing 0.5% AlN nanoparticles will has increased by 1.57 times at 60 ºC .

Guan et al. [5] (2014) CFD used nano particles adding to transformer oil in there study. Also, studied the forced and natural convections, and effect their on temperature, velocity and density. Their study recognized to improve efficiency of the heat transfer by the nanoparticles. For elements, Position and oil temperature.

R. SRILEKHA [6] (2016) the aimed from there studied to study the distribution the velocity and temperature in the transformer. MATLAB program used to study oil through modeling in transformer by using of two methods. To study the effect of temperature and velocity on the flow, in the first; focused on the derived Equation from preceding work on flow and temperature distribution of cooling oil. The second; the commons problem to deal this case is the distribution enhancement, flow and solved by using a numerical method. This study has been provided that, the solutions are available in details of construction that can be applied in a preparation.

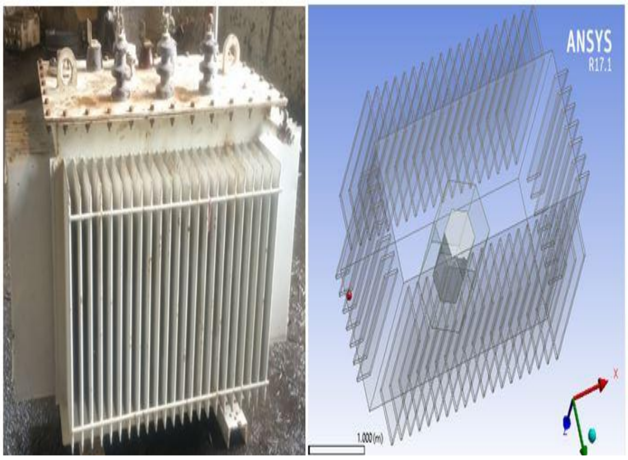
Mushtaq I. Hasan [7] (2017) has been studied, electrical transformer distribution the thermal behavior of the influence of the air temperature was numerically investigated. A 250 KVA a model of Transformer distribution was chosen. Also, studied in range of cover temperature to weather situations of hot places. Nano-fluids were used as a transformer oil-based as a cooling medium in its place of pure transformer oil. A solid particles of nano-fluid (Al_2O_3, Cu, SiC and TiO_2) to comprise with different volume ratio. Its good thermal structures the nanoparticles principal to increase in the breakdown voltage and dielectric voltage of the oil. The results display that, using of transformer oil- as a cooling medium in its place of the pure oil cooling, lead to increasing the cooling performance of the transformer by dropping the temperature of the electrical transformer.

Mushtaq I.Hasan[8] (2017) numerically studied of the electrical transformer, by a cooling medium as transformer oil based on suspension instead of the pure transformer oil. Cooling transformer oil contains of a micro capsules, enclosing by phase change materials, surrounded by a cover made of the polymers MEPCM, mixed with pure transformer oil. Contributes to a cooling of the transformer parts further pure oil, and thus will increase the cooling efficiency of the electrical transformer. Also, the increase in operating life of transformer parts. A CFD code used to solved model used, where the microcapsule contains paraffin wax as a phase change material. Which individual and solitary inside the capsule after absorbing heat from the cooling oil. The results revealed that, a reduction clear in temperature of a mix and in an interior parts of transformer. Also, thus will preserve to the dielectric oil and including oil for collapse, and thus defend to save transformer from loss.

Mushtaq I. Hassan et al. [9] (2018) used PCM as a cooling mediums at a different conditions. They established that, using PCMs to improving the performance of the cooling in a micro heat sink. The phase change material should be selected according to its melting temperature according to the certain application as different phase change Martials caused different values of reduction in heat sink temperature in range of ambient temperature due to difference in melting temperatures of PCMs.

2- Problem description:-

A 100 KVA: distribution transformer is occupied to study a case in this paper. Which is used usually in network electricity of Iraqi. Picture at Fig. 1a shows a real transformer. While Fig. 1b represents a schematic drawing to illustrate the outer view of this transformer from workbench ANSYS R17.1. The transformer involves of (coils and core assembly), its consists of three copper coils, and a steel core linking it. All these items are immersed in transformer oil, contained in the body of transformer which delivered by fins to increase area of the heat transfer. The transformer oil formed two roles important, the heat generated of a cooling intermediate transfer in coils and core into external walls to disperse it to the external and electric insulator. According to the standard (IEC60076); the heat generated in the transformer at a full load state is about 1850 W. This heat generated requisite be excluded to maintain the temperature of the oil at a level acceptable. The properties of oil used in transformer are listed in Table1 (1). In this paper, the transformer is simulated numerically, since a model of transformer contains from bar heater has showed the coils and core, and the amount of heat generation is practical consistent to real heat losses added in a real transformer. In this paper, the unusual approaches used to rise the cooling efficiency of transformers by using PCM. It's exclude using 10 kg of the PCM, as shield round the hexagonal bar heater by a different types of PCM.



(a) (b)

Fig. 1. distribution transformer (a) Picture for100 KVA transformer, (b) schematic figure for 100 KVA Transformer

3- Governing equations:-

The governing equations designed for solving this model, which are represented by continuity, momentum and energy equations. Which can be written as a following [10][11][12][13]:

The continuity equation:

$\nabla V=0$ … (1(

Momentum equation:

$\rho(V.\nabla V) = -\nabla P + \nabla.(\mu \nabla V) + \frac{\rho-\rho\infty}{\rho\infty}$ …(2)

Energy equation:

$\rho C_p(V.\nabla H) = K \nabla^2 T$ …(3)

The enthalpy (H) of the PCM is specified by Eq. (4); and calculated as: the sum of the latent heat (ΔH), and the sensible heat (he) of the PCM

$H=\Delta H + he$ … (4)

The sensible heat is defined by Eq. (5), where $h_{ref.}$ is the reference enthalpy at $T_{ref.}$

$he=h_{ref.}+\int_{T_{ref.}}^{T} CP_F\, dt$ ...(5)

The energy (sensible & latent) deposited in PCM (Q) can be determine by (6):

$Q=\int_{Ts.}^{Tpc} mCpsdT+ m\Delta H +\int_{Tl.}^{Tpc} mCpldT$ … (6)

The latent heat for PCM(ΔH) is defined by Eq. (7) as a function of the melting fraction (β) and the fusion PCM (L). The melting mass fraction (β): is defined as ratio mass of melted PCM; to the total mass of PCM in the mixture. The PCM start to melt at $T_{solidus}$ and finishing melting at $T_{liquids}$; where the liquid fraction which can be vary from 0.

4- Boundary conditions (B.C):-

The boundary conditions used to close the model are:

1- Constant B.C heat generation applied on core and coils

2- Mixed (convection and radiation) B.C is applied on all outer walls.

3- The walls of two separated zones solid / liquid are preserved as a (coupled) conjugated heat transfer.

5- Properties of (PCMs) phase change materials:

A phase change materials are substances with a high heat of fusion, which are melting and solidification at a certain temperature, the PCMs had ability of storage and release large quantities of energy. Heat is released or absorbed when material changes from a solid to the liquid and vice versa. The PCMs continues to absorbing heat without any significant rise in a temperature until all the materials are converted to a liquid phase. When ambient temperature falls around the liquid material, the PCM solidifying, releasing its stored heat. A large number of PCMs are presented in any essential temperature range from −5 C° up to 190C°. They store from 5 to 14 times more the heat per unit volume, compared with conventional storage of the materials such as rock, water or masonry [13] the PCMs are classified to: organic, in-organic and eutectics. The properties of the phase change materials used in this paper are listed in table 1 below [14, 15, and 16].

Table1 Properties of materials studied in this paper

Material	Thermal conductivity (W/m.K)	Specific heat(kJ/kg.K)	Density (kg/m3)	Temp. C°		Melting heat(kJ/kg)	Viscosity for liquid phase (kg/m.s)
				Ts	TL		
Transformer oil	0.109	2	880	—	—	—	0.0124
Paraffin wax	0.212	2.3	880	50	57	173.6	0.0063
RT44	0.2	2	802	37.5	42.9	141.7	0.003
P116	0.21	2.1	830	50	50	190	0.00076
Aluminum	273	8.71	2719	—	—	—	—

6- Numerical Solution:

The above model was solved for boundary conditions and numerical equations using FVM. A simple algorithm used to solve the problem and the difficulty of pairing to flow computing variables by solving equations (continuity, momentum and energy). The mesh selected to solve this model by identifying the size of the network since the improvement of the mesh made to find the appropriate mesh size provides a high resolution of the solution. Six mesh sizes were used to make the results and a mesh independent of the average oil converter temperature for different mesh used in Table 2, at ambient temperature = 37 companies. It can be seen that through this table, the mesh size solution becomes independent after the fifth grid. Therefore, the fifth mesh size used in all future solutions. Fig. 2 shows the numerical area and mesh used. Meshes in Table 2, the ambient temperature is revealed to = 310 K. Table 2 shows a different selection of meshes. It can be seen that through this table, the mesh size solution becomes independent after the fifth grid. Therefore, the fifth mesh size used in all future solutions.

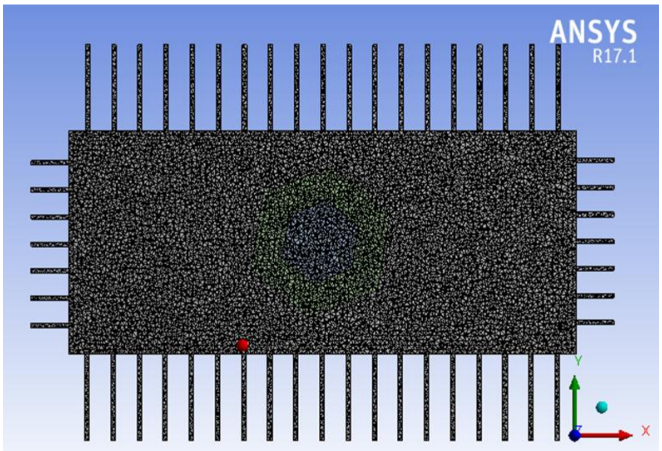


Fig. 2 View half-outer mesh used for computational model.

Table 2 Grid independent study

Mesh	Average oil temperature (K)
Mesh1 (Number of nodes = 106851)	514.4
Mesh2 (Number of nodes = 152831)	484.5
Mesh3 (Number of nodes = 246821)	444.78
Mesh4 (Number of nodes = 320681)	394.17
Mesh5 (Number of nodes = 462700)	341.021
Mesh6 (Number of nodes = 627681)	340.812

The used 10^{-6} as divergence conditions to controller the mathematical result for both energy, and momentum equations.

A 3-D model of electrical transformers with PCMs is numerically resolved. First, the model is dissolved in oil as a coolant with fixed properties chosen to allow ambient temperatures. After that, the solution is repeated by using PCMs as a cooling unit instead of oil The model used in this study was validated with a numerical study to verify the validity of this model, and the results attained are compared with the current model. The numerical model in [8] represents the 250KVA transformer chosen for the study. The heat generation in the case of full load in the converter is 1 KW of file and 0.5 KW of each core. In this study, the maximum temperature of the liquid was measured by the MEPCM suspension value of 5% concentration with external temperature (30 to 45). Figure (3) shows the comparison between the data [19] and the current numerical model of temperature. Note that the result between both is acceptable.

Fig. 3 comparison between the numerical results of [8] and results of present model

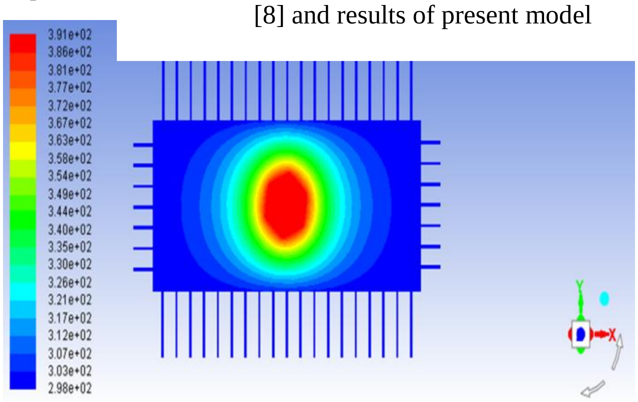


Fig.4 Contour of temperature on (x-y) plan at middle height of transformer

The temperature in Fig. 4 and 5 at x-y and y-z shows an average height and width of the corresponding converter of pure cold oil at a temperature outside 25 C°. These shapes are clear that the temperature distribution starts from the maximum value of the adjacent surface of the heater to the outer walls with a minimum of transformer values due to ambient air temperature due to heat transfer from the heater to the outside air through the oil transformer.

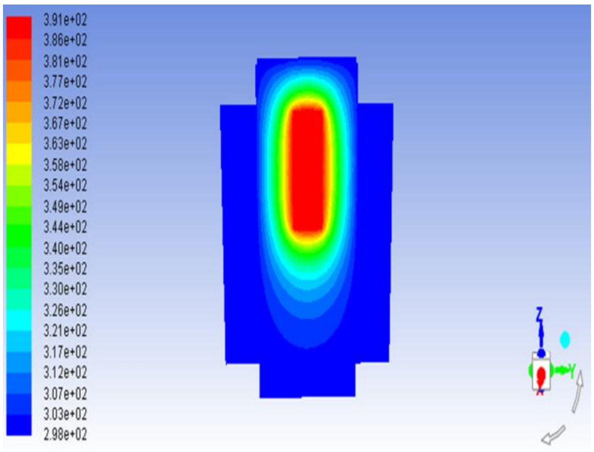


Fig.5 Contour of temperature on (y-z) plan at middle width of transformer

The **Fig. 6** displays the temperature counters for the use of 10 kg of PCM, as a shield around windings, and coils (wax) at 25 C^{o}. Compared to the figures (4 and 5), a low temperature that starts from the features of host temperature and limits is evident. Because PCM is used as storage heat, in this case the latent heat used is accessible wherever the pack oil is pure and without latent heat. The transfer of heat generation from coils and files to the oil and to the outer environment of the external temperature at some time is higher than the average temperature of the transformer. Also, some are slightly different in PMC profiles found for another because of the properties of these materials.

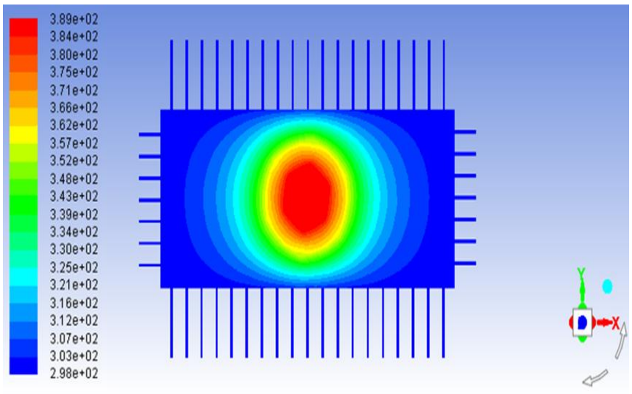


Fig.6 Contour of temperature on (x-y) plan at middle height of transformer with PCM shield

Fig. 7 presented the variation of average temperature of transformer with a shield for deferent, kinds by using of PCMs: (wax, RT44, and P116), by transformer oil. Constant heat generation: (1.850) kW of mixed boundary conditions: (convection and radiation), and heater is used. The ambient temperatures used in the boundary state are four values: (25, 37, 45, 55) K. Using an oil transformer shield and PCMs instead of pure transformer oil for this case of displays in this figure (0), represents the state of the pure oil transformer. We can see that from these figures, the average temperature has decreased using the amount of PCMs used. In addition, it can be realized that the lowest average temperature is obtained when different PCMs are used for each different material in ambient temperature. Due to the difference in temperature melting range to study PCMs which result in a difference in the dissolved amount and PCM melting process in the variable values of ambient temperature. This indicates the suitability of some PCMs depending on ambient working temperature. Since the temperature of the adapter is reduced through the selected PCMs depends on ambient temperature.

Fig. 7 Variation of the average temperature of transformer with a shield of PCMs used at different of ambient temperature

Fig. 8 The maximum transformer temperature varies with the external air temperature of the pure oil represented by this form. It can be realized that, from this figure, in all cases, the maximum temperature increased by increasing air temperature. Also, if PCM is used with oil, the maximum temperature is less than the temperature of the pure oil in the same conditions. Due to, an additional amount of latent heat absorption due to PCM melting.

Fig. 8 variation of the maximum temperature of transformer with a shield of PCMs used at a different of ambient temperature

Fig. 9 Shows the difference between the sensible heat of the transformer for three types of PCMs (Paraffin Wax, RT44 and P116); at an external temperature (298, 310, 318, 328) K. This sensible temperature provides an indication of the amount of sensible heat dissipating in ambient air. From this form, we can realize that the amount of heat transferred when using PCMs is higher than that of pure oils. Because, thermal conductivity of PCMs leads to an improvement in heat dissipation process. In addition, the results showed that paraffin wax above the specified range provides higher heat transfer due to its high thermal properties.

Fig. 9 Variation of sensible heat of transformer with a shield of PCMs used at different of ambient temperature

Fig. 10 Expressions of variation (sensible temperature and latent heat); when placing PCM inside the transformer at different ambient temperature. This can be limited, of these forms; the very appropriate latent heat in the transformer, the mass fracture at high temperature will increase. The result of the increase in latent heat and the collection of latent and reasonable heat is equal to total heat as described in the above forms. PCM added to the heat at a reasonable temperature so heat transfer of the cores and files it increases. In addition, if PCM devices are increased, it means an increase in heat stores that will improve the heat transformer of the electrical transformer.

Fig. 10 variation of total heat of transformer with the shield of PCMs used at a different of ambient

8- Conclusions:

Phase change materials studied numerically in this paper, different types of PCM (waxes P116, RT44 and Paraffin); are selected at different ambient temperatures. From the results obtained, the following conclusions can be made:

1- PCMs indications to decrease temperature of transformer related with the case of pure oil.

2 - Lower average temperature with increased PCM mass; due to increase in the amount of added PCMs.

3-PCMs dependent on the environment conditions.

4- PCM as a lead shield to decrease the maximum temperature compared to pure cooling oil.

9- **References:-**

[1] Jon G., Carlos R., Gorka S., Alejandro R., Josu I., Luisdel R., "Numerical modelling of natural convection of oil inside distribution transformers" Applied thermal engineering Vol. 31, No. 4, PP. 493-505, 2011.

[2] Carlos M., Jose G., Madalena M., "CFD analysis of core type power transformers", 1st International

Conference on Electrical Distribution, Vol. 2, No. 0361, PP. 6-9, 2011.

[3] M. Srinivasan, “Prediction of Transformer Insulation Life with an Effect of Environmental Variables”, International Journal of Computer Applications, V. 55, No.5 pp. 0975-8887, 2012.

[4] M. Dong,1 L. P. Shen,2 H. Wang,2 H. B. Wang,2 and J. Miao, “Investigation on the Electrical Conductivity of transformer oil-based nanofluid”, Hindawi Publishing Corporation Journal of Nanomaterials Volume 2013.

[5] Guan, Weimin, et al. "Finite element modeling of heat transfer in a nanofluid filled transformer." *IEEE Transactions on Magnetics* 50.2 (2014): 253-256.

[6] Jesto Th., Srivatsa P., Ramesh K., Rajesh B., " Thermal Performance Evaluation of a Phase Change Material Based Heat Sink: Numerical Study", Procedia Technology, Vol. 25, PP. 1182 – 1190, 2016.

[7] Mushtaq Ismael Hasan-“Using the transformer oil-based nanofluid for cooling of power distribution transformer” International Journal of Energy and Environment, Volume 8, Issue 3, 2017 pp.229-238.

[8] Mushtaq Ismael Hasan-“Improving the cooling performance of electrical distribution transformer using transformer oil–Based MEPCM suspension." Engineering Science and Technology, an International Journal 20.2 (2017): 502-510.

[9] Hasan, Mushtaq Ismael., and Hind Lafta Tbena. "Using of phase change materials to enhance the thermal performance of micro channel heat sink." *Engineering Science and Technology, an International Journal* (2018).

[10] Mushtaq I. Hasan, Abdul A. Rageb, Yaghoubi M. , Homayony H., "Influence of channel geometry on the performance of counter flow micro channel heat exchanger", Int. Journal of Thermal Sciences, Vol. 48, 1607-1618, 2009.

[11] Mushtaq I. Hasan, "Numerical investigation of counter flow microchannel heat exchanger with MEPCM suspension ", Applied Thermal Engineering, Vol. 31, pp.1068-1075, 2011.

[12] Mushtaq I. Hasan, Hayder M. Hasan, Ghassan A. Abid, "Study of the axial heat conduction in parallel flow microchannel heat exchanger ", Journal of King Saud University – Engineering Sciences, Vol. 26, pp. 122–131, 2014.

[13] Nivesh A., Mahesh D., " Heat Transfer Analysis of Micro Channel Heat Sink", International Journal of Science and Research (IJSR), V.2, Issue1, pp.171-181, 2013.

[14] Atul Sh. Kumar, Vineet V. Tyagi , Chen R. Changren , Dharam B., " Review on thermal energy storage with phase change materials and applications, " Renewable and Sustainable Energy Reviews, Vol. 13, pp. 318–345,2009.

[15] Kenisarin M., Mahkamov K. ,"Solar energy storage using phase change materials", Renewable and Sustainable Energy Reviews, Vol. 11 , pp. 1913–1965,2007.

[16] Santosh K. Sahoo, Prasenjit R., Mihir K. Das, " Numerical study of phase change material based orthotropic heat sink for thermal management of electronics components", Int. J. of Heat and Mass Transfer, Vol. 103, pp. 855–867, 2016