NUMERICAL INVESTIGATION ON HEAT PIPE WITH TRITRIACONTANE NANO FLUID TO ENHANCE HEAT TRANSFER BY USING DIFFERENT GLASS MATERIAL ON EVAPORATION SECTION

Adil Amin [1], Prof. Rohit Choudhary [2]

Mtech.Scholar[1],HOD[2]
Department of Mechanical Engineering[1,2,]
Bhopal Institute of Technology and Science, Bhopal, India

Abstract

In the current work, the CAD model of heat pipe has been developed by using UNI-GRAPHICS NX-8.0. so that you can take a look at diverse parameters affecting the thermal and segment transformation overall performance of heat pipe. Different varieties of glass substances of heat pipe were used with exceptional profile i.e. Inside the fluid flow (Tritriacontane) nano fluid on heat pipe. We found that they gives better temperature distribution and mass transformation in capillary tube of heat pipe. The simulations have been completed at a variable temperature w.r.t. Time.

Keywords— *Heat pipe, Temperature, Borosilicate, CFD, copper pipe, Tritriacontane*

I INTRODUCTION

A heat pipe is a warmness transfer device that combines the principles of each thermal conductivity and section transition to correctly transfer warm temperature among solid interfaces. At the new interface of a warm temperature pipe a liquid in touch with a thermally conductive robust ground turns into a vapor via absorbing warmness from that floor. The vapor then travels along the warmth pipe to the bloodless interface and condenses decrease lower back proper into a liquid – freeing the latent heat. The liquid then returns to the recent interface through capillary action, centrifugal strain, or gravity, and the cycle repeats. Due to the very immoderate heat transfer coefficients for boiling and condensation, heat pipes are incredibly powerful thermal conductors. The powerful thermal conductivity varies with warmth pipe length, and may method 100 kW/(m·K) for long heat pipes, in evaluation with approximately 0.Four kW/(m·K) for copper.

II HEAT PIPE EVACUATED TUBE COLLECTORS

Heat pipe evacuated tube collectors, a sealed heat pipe, usually made of copper to increase the collectors efficiency in cold temperatures, is attached to a heat absorbing reflector plate within the vacuum sealed tube. The hollow copper heat pipe within the tube is evacuated of air but contains a small quantity of a low pressure alcohol/water liquid plus some additional additives to prevent corrosion or oxidation.

This vacuum enables the liquid to vapourise at very lower temperatures than it would normally at atmospheric pressure. When sunlight in the form of solar radiation hits the surface of the absorber plate inside the tube, the liquid in the heat pipe quickly turns into a hot vapour type gas due to presence of the vacuum. As this gas vapour is now lighter, it rises up to the top portion of the pipe heating it up to a very high temperature. The top part of the heat pipe, and therefore the evacuated tube is connected to a copper heat exchanger called the “manifold”. When the hot vapours still inside the sealed heat tube enters the manifold, the heat energy of the vapour is transferred to the water or glycol fluid flowing through the connecting manifold. As the hot vapour looses energy and cools, it condenses back from a gas to a liquid flowing back down the heat pipe to be reheated.

The heat pipe and therefore the evacuated tube collectors must be mounted in such a way as to have a minimum tilt angle (around 30o) in order for the internal liquid of the heat pipe to return back down to the hot absorber plate at the bottom of the tube. This process of converting a liquid into a gas and back into a liquid again continues inside the sealed

heat pipe as long as the sun shines. The main advantage of Heat Pipe Evacuated Tube Collectors is that there is a "dry" connection between the absorber plate and the manifold making installation much easier than with direct flow collectors. Also, in the event an evacuated tube cracking or breaking and the vacuum becoming lost the individual tube can be exchanged without emptying or dismantling the entire system. This flexibility makes heat pipe evacuated tube solar hot water collectors ideal for closed loop solar designs as the modular assembly allows for easy installation and ability to easily expand by adding as many tubes as you want.

III Heat pipe materials and working fluids

Heat pipes have an envelope, a wick, and a going for walks fluid. Heat pipes are designed for extremely long time operation without a upkeep, so the warmth pipe wall and wick need to be well suited with the running fluid. Some material/working fluids pairs that look like well-matched aren't. For instance, water in an aluminum envelope will develop large quantities of non-condensable gas over some hours or days, preventing ordinary operation of the warmth pipe.

1)Typical use of warmth pipe: one end (the evaporator) is hooked up to the warmth supply and the opportunity stop (the condenser) to the warmth sink. The center section (the adiabatic section) is insulated.

2)As liquid is vaporized at the evaporator, the vapor stress builds up, forcing vapor to drift axially along the middle middle to the condenser .

3)Vapor condenses on the condenser. Liquid is drawn once more to the evaporator through the capillary pressure alongside the grooves.

4)The strain distinction some of the vapor and liquid degrees is sustained through the ground anxiety strain of the fluid.

5)Passive – no outdoor pumping power is needed; the waste heat gives the using pressure for the fluid go with the flow

IV LITERATURE REVIEW

M.S. Abd-Elhady et al. [1] - the studies improves the heating functionality of evacuated tubes that carries warmth pipes. Thermal oil is inserted inside the evacuated tube so as to enhance the charge of warmth transfer, such that the mode of warmth switch from the internal surface of the evacuated tube to the warm temperature pipe becomes convection through the oil, as well as conduction thru the set up fin. The finned floor has been modified through using a foamed-copper. An experimental setup has been advanced to study the have an effect on of oil and foamed metals at the overall performance of evacuated tubes with warmness pipes. It has been located that the bulb temperature in addition to the heating overall performance of the evacuated tube warmness pipe has improved in case of inserting oil inside the evacuated tube and converting the finned floor with foamed copper. Also, the thermal oil acts as a warmth storage.

Sarvenaz Sobhansarbandi et al. [2]-this investigation to Solar water warmers (SWHs) are a nicely-mounted renewable power era that have been significantly adopted spherical the sector. In this check we've considerably advanced the Evacuated Tube solar Collectors (ETCs) with the useful resource of using the ‘‘dry-drawable" Carbon Nanotube (CNT) sheet coatings to growth the solar power absorption and Phase Change Materials (PCMs) to growth the heat accumulation for software program in solar water warmers. The proposed solar collector uses a section alternate fabric specifically Octadecane paraffin, with melting temperatures of 28 C that is classified as non-poisonous with longterm chemical balance PCM. As PCMs specially in powder shape might not be powerful through the use of itself due to the poor warm temperature switch price, low thermal diffusivity and thermal conductivity, via using combining CNT layers with the immoderate thermal diffusivity and thermal conductivity study to section exchange materials, we're capable to overcome the shortcomings of PCMs and design an contemporary and inexperienced solar water heater. With the modern-day technology, we're capable of offer a close to best black body floor, soaking up a most of 98%, among six hundred and 1100 nm, of solar mild setting the floor, and supplying more spectral absorption which improves the general performance of the sun heater. Applying CNT sheets at the side of PCM allows warmness garage without delay at the collector for a more steady output, even on a cloudy day and extended output of heat at night time time.

S. SivaKumar et al.. [3] - the investigation the Renewable deliver of strength is the destiny power supply that meets out our name for for energy. In this sun electricity is one of the top property. The harnessing of the solar electricity may be achieved in each procedures Solar (PV), Solar Thermal. Solar thermal unearths more appropriate for domestic desires including Space Heating, Cooling, Hot water systems, drying. Hence the need for generating thermal power from the collectors is essential. Out of all the thermal creditors the evacuated tube solar collector (ETSC) is located to have the exceptional performance with low solar insolation. In this paper the evacuated tube is modelled with warm temperature pipe for the enhancement of the heat generated from the collector. The goal of this research is to format and look into the heat switch evaluation of Heat Pipe Evacuated Tube sun collector is made from Borosilicate glass with length 1.8m and zero.058m and 0.049m diameter of outside and interior tubes for the Coimbatore region.

A.E. Kabeel et al. [4] - the investigation Modified coaxial warmth pipes had been designed and manufactured to beautify the thermal universal performance of the glass vacated solar creditors. Heat pipes have been product of two concentric copper tubes just so the annulus volume location among the concentric tubes turn out to be charged with refrigerant. In addition, the air because the working fluid at 4 unique mass float expenses 0.0051, zero.0062, zero.007 and zero.009 kg/s flows thru the inner tube of the warm temperature pipe to the flow via the annulus between the warmth pipe and glass evacuated solar tubes. The impact of the tilt attitude of the evacuated tube on thermal overall performance of the evacuated sun tube collector was tested to acquire the maximum beneficial tilt attitude all through the experiments length. The influence of filling ratio for the 2 styles of refrigerant R22 and R 134a on the thermal efficiency of the coaxial heat pipe sun collector at submitting ratio variety from 30% to 60% changed into achieved experimentally. Results display that the maximum improved in the thermal overall performance reached sixty seven% just like without heat pipes at mass glide rate zero.009 kg/s. The test outcomes showed similarity among the two refrigerants.

Piotr Felinski and Robert Sekret [5] - this investigation a unique idea of the use of a segment exchange cloth (PCM) to save thermal strength immediately inside a warmth pipe evacuated tube collector ready with a compound parabolic concentrator (CPC). The remarkable insulating homes of evacuated tubes and the use of latent warmness are huge advantages of a PCM included evacuated tube collector/storage (ETC/S) over conventional sun water warmers. However, at some stage within the charge cycle of the ETC/S, direct sun radiation simplest reaches the uncovered vicinity of the evacuated tubes, which ends up in uneven heating of the PCM because of a decrease strength input inside the shaded region. This may be prevented through using a CPC to concentrate the sun radiation on the shaded place of the evacuated tubes, thereby raising the temperature of the PCM and quantity of stored warm temperature. Therefore, an advanced, thin aluminum sheet was used as low charge CPC with a awareness ratio of one.2x. Technical grade paraffin with an onset melting temperature of fifty one.24 C grow to be used as the PCM. The outcomes from this examine confirmed that the utility of the CPC brought on the temperature of paraffin on the shaded facet of the evacuated tubes to growth extra unexpectedly, mainly in the course of and after melting of the paraffin. Furthermore, the use of a CPC in a PCM included ETC/S advanced the not unusual gross charging performance from 31% to 36% and the maximum charging overall performance from forty% to 40 9%.

Meysam Faegh and Mohammad Behshad Shafii [6] - this studies a novel concept of storing the latent warmth of condensing vapor in solar stills by means of phase exchange substances (PCMs) as a thermal garage is experimentally investigated. During the daylight, the generated water vapor by way of manner of the solar power, is finished to an outside condenser complete of PCM to be condensed. The wasted latent heat is absorbed through PCM and thereby stored. It is clearly really worth noting that there may be no direct contact between the salinewater and the PCM, therefore, the solar strength is not immediately saved within the PCM. In the night time, the electricity stored in the PCM is transferred as heat to the saline water through warmth pipes and allows the desalination system to keep. Several checks were run to investigate the performance of the system. The effects located out that the presence of an outdoor condenser packed with PCM and prepared with warmness pipes in a solar although with evacuated tube creditors, makes the desalination technique hold after the sundown with out causing a decrease within the yield for the duration of the daylight. The yield will increase via 86% compared to the yield of the machine with out PCM and reaches to six.555 kg/m2 day with the overall performance of fifty%.S

Mohamed Hany Abokersh et al.. [7] -This investigation Space and weight requirements coupled with time delay between energy manufacturing and consumption represent first-rate boundaries inside the path of in addition deployment of ordinary solar water heating structures in modern homes with restrained space. Therefore, a brand new compact U-pipe evacuated tube solar collector (ETC) incorporated with paraffin wax (ALEX WAX 600) for energy garage is supplied inside the current look at. The ALEX WAX 600 is an herbal chemical-primarily based phase trade

material (PCM) having an average melting temperature of 60 C and a thermal conductivity of zero.21 W/m K. The key issue of the superior machine is the elimination of complete structures additives through way of storing the power inside the evacuated tube itself via the usage of paraffin wax. Due to the low thermal conductivity of paraffin wax, warmness transfer plate (fin) with a place of 0.1251 m2 is integrated within the proposed machine. The present study investigates the superior gadget beneath configurations; un-finned and finned U-pipe evacuated tube sun collector element by means of facet with a fashionable pressured recirculation solar water heating system (FSWHS) under the equal operation and climate situations. The operation of the solar water heating structures is studied at some stage in the on-name for operation underneath a simultaneous operation and a actual water consumption profile. The results make clear the favorable normal performance of the developed compact solar water over the typical FSWHS for the duration of extremely good operation scenarios and weather conditions because of their low thermal inertia. Furthermore, using fin within the developed machine has a enormous impact on improving the heat transfer traits of the PCM and complements the overall device stability. During simultaneous operation tests, the entire effective power discharged for the un-finned gadget is higher than FSWHS via 35.Eight% under clear day climate situations. However, the finned device is better than FSWHS by means of 47.7%. The simultaneous longterm predictions primarily based totally on regression modeling show that the commonplace annual efficiency is seventy one.Eight%, 80 five.7% and forty.Five% for the un-finned, finned and FSWHS systems, respectively. During actual water consumption profile checks, the each day tool performance is, 33%, 26% and 20% for the un-finned, finned and FSWHS structures

Saıf ed-Dın Fertahi et al.. [8] -This paper outlines three research that were accomplished to extend the lifespan of the horizontal garage tank, thru the definition of a suitable cloth and an pinnacle of the line format. The maximum essential conclusions of the evaluation are that the satisfactory configuration which avoid the arrival of the strain awareness zones is the configuration (c), wherein Ri ¼ 11mm and Re ¼ 14 mm, due to the fact the stress on the tank's shell became better carried out. Moreover, the effect of the fabric's choice turned into finished, and it changed into located that stainless-steel is the closing material. Last but now not least, a tough and fast of simulations have been accomplished to investigate the tank shell thickness on which the thermo-mechanical constraints were implemented. The thickness t ¼ 2 mm became supplying an pinnacle of the road mechanical behavior in regards to the studied running situations.

Vahit Corumlu et al.. [9] - this research the specified thermodynamic evaluation of an incorporated manner based on warmth pipe evacuated tube solar creditors for hydrogen production is provided for greater efficaciously way designs. An incorporated technique includes the sun heat pipe collector, photovoltaic panels, PEM electrolyzer and Linde-Hampson hydrogen liquefaction system are taken into consideration and analyzed thermodynamically for hydrogen manufacturing and liquefaction desires. The active and exergetic efficiencies of this integrated procedure are calculated as zero.2297 and 0.1955, respectively. Based on the parametric take a look at, the effectiveness of the solar strength based covered way is also exceedingly relying at the sun flux and ambient conditions

Guillermo Martínez-Rodríguez et al.. [10] - the studies the layout and specification of solar collector networks for the capture of solar radiation and its transformation into thermal strength to be used in low electricity intensity techniques. All glass evacuated tube solar lenders are the form of technology considered in this paintings. Target temperature and heat load are the format dreams within the layout of solar collector networks and they may be carried out with the resource of specification of format variables, specifically: a) quantity of creditors in series in a row and, b) sort of rows in parallel. The variability of ambient conditions is accounted for by using the specification of the essential aspect situations for the layout of the network. From the thermal factor of view, the variety of solar collectors or warmth transfer floor place required to obtain the objectives relies upon on the ambient situations selected for the design. The concentrated on approach for the specification of the community structure is primarily based mostly on using a thermal version. The numerous layout alternatives available to the fashion dressmaker to specify the variety of sun lenders in a row, are furnished in a graphical manner as a function of mass go with the flow price, inlet temperature, sun radiation depth and goal temperature.

Tahmineh Sokhansefata et al.. [11] -The investigation a thermoeconomic evaluation of two specific sun hot water systems primarily based on forms of flat plate collector (FPC) and evacuated tube collector (ETC) are studied beneath the cold weather conditions of Iran. The annual solar collector energy output and the creditors' output temperature are calculated the usage of the TRNSYS16 software. As a quit result, it's miles determined that the inlet temperature and weather conditions are the two primary variables which impact at the collector average overall performance. Finally, in line with the thermal and economic assessment, the general overall performance of ETC machine is 41% better than the FPC systems, and the every year beneficial strength advantage of ETC is 30% extra than that of FPC in bloodless

climate. So, making use of ETC in cold weather is usually recommended. Additionally, this simulation may be extendable and relevant for each area with any climatic scenario..

Amir Amin et al. [12] -Finding a choice to save industrial wasted heat for later use which will lessen strength utilization has been on the rise in latest years. This paper investigates the capability of latent warmness TES (Thermal Energy Storage) machine using PCM (Phase Change Material) to store/launch a big quantity of energy in a small quantity as compared to realistic heat TES gadget. In this paintings, the problem of the low conductivity of PCMs has been addressed with the aid of way of the usage of an embedded finned water-charged warmness pipes into the PCM bulk. Both warmness pipes and the PCM tank used on this studies have been made from 316 L stainless-steel. The PCM used in this work have become PLUSICE S89, which has a melting temperature of 89 C and crystallization factor of seventy seven C. The evaporator section of the warmth pipe was heated by means of condensing a steam glide. The warm temperature that become absorbed within the evaporator phase changed into then discharged to the PCMs with the aid of the warm temperature pipe multi-legged finned condenser. Tests have been carried out for every charging (melting) and discharging (crystallization) of PLUSICE S89. It became discovered that the thermal resistance posed via PCM at a few stage within the discharging diploma became higher in comparison to that in the charging method

V MODELING AND ANALYSIS

Design procedure

The procedure for solving the problem is

1 Modeling of the geometry.
2 Meshing of the domain.
3 Defining the input parameters.
4 Simulation of domain.

Finite volume analysis Heat pipe

Analysis Type - Fluent and Modal.

Preprocessing

Preprocessing include CAD model, meshing and defining boundary conditions.

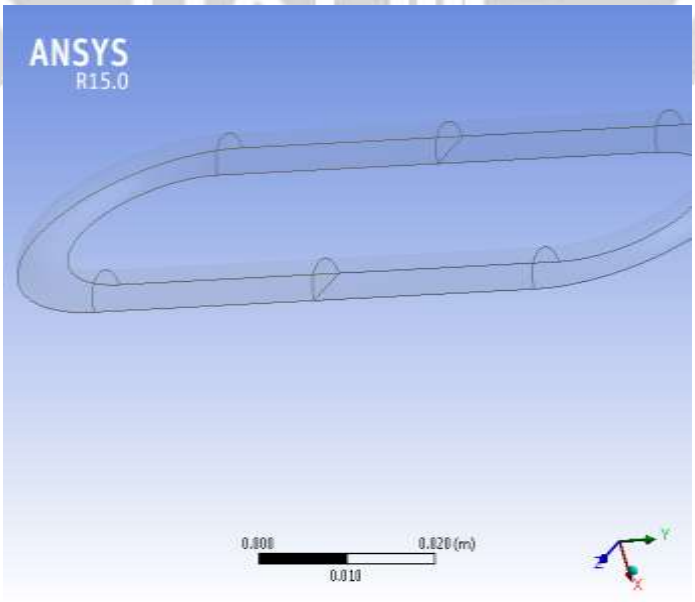

***Figure**: 5.1 CAD model of heat pipe.*

VI RESULT AND DISCUSSION

A three-dimensional model has been developed to investigate heat transfer in the heat pipe for heat removing process. A series of numerical calculations have been conducted using commercial CFD code FLUENT 15.0.The results are presented in order to show the effects of temperature distribution with respect to different e material of evacuated glass tube

Temperature distribution on heat pipe with Soda lime Silicate Glass evacuated tube:
Table 4.2 Temperature variation w.r.t. Time of heat pipe

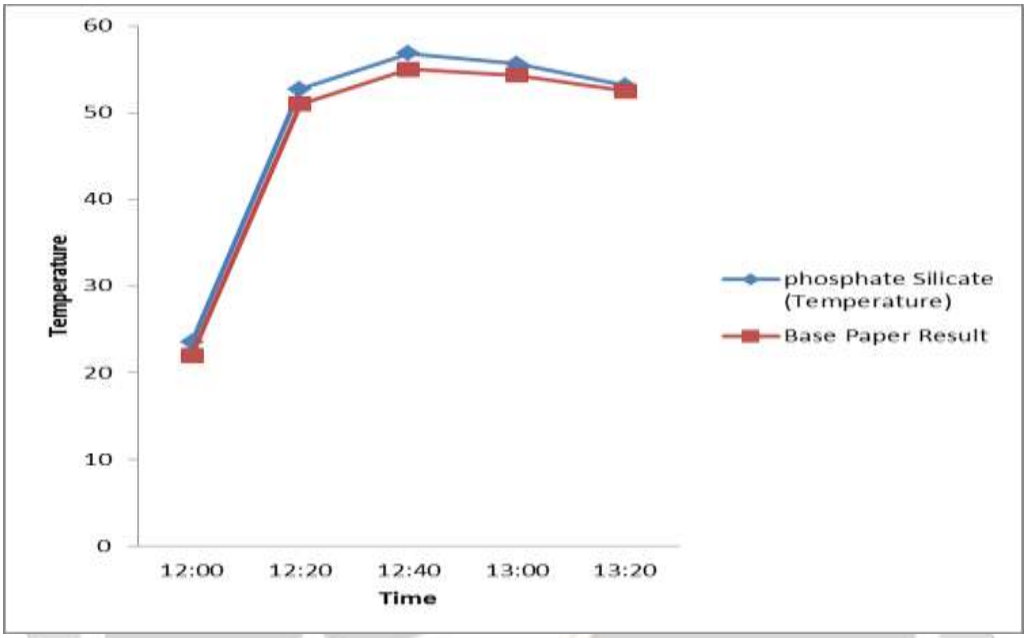

Figure 4.5 Temperature variation of Soda lime silicate glass evacuated tube on time

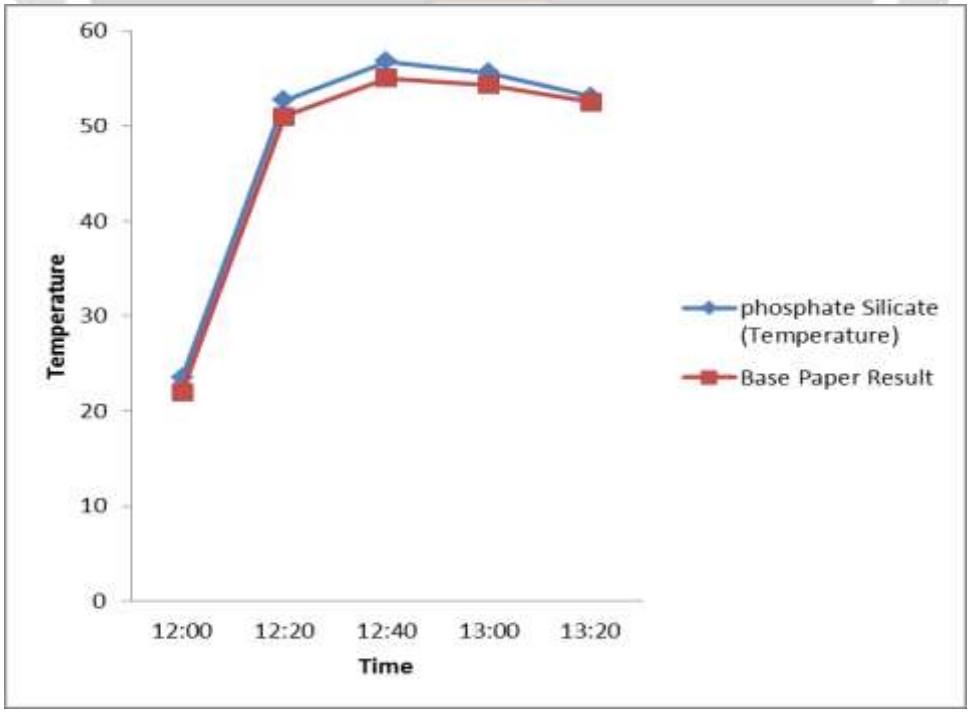

Figure 4.11 Temperature variation of Soda lime silicate glass evacuated tube on time.

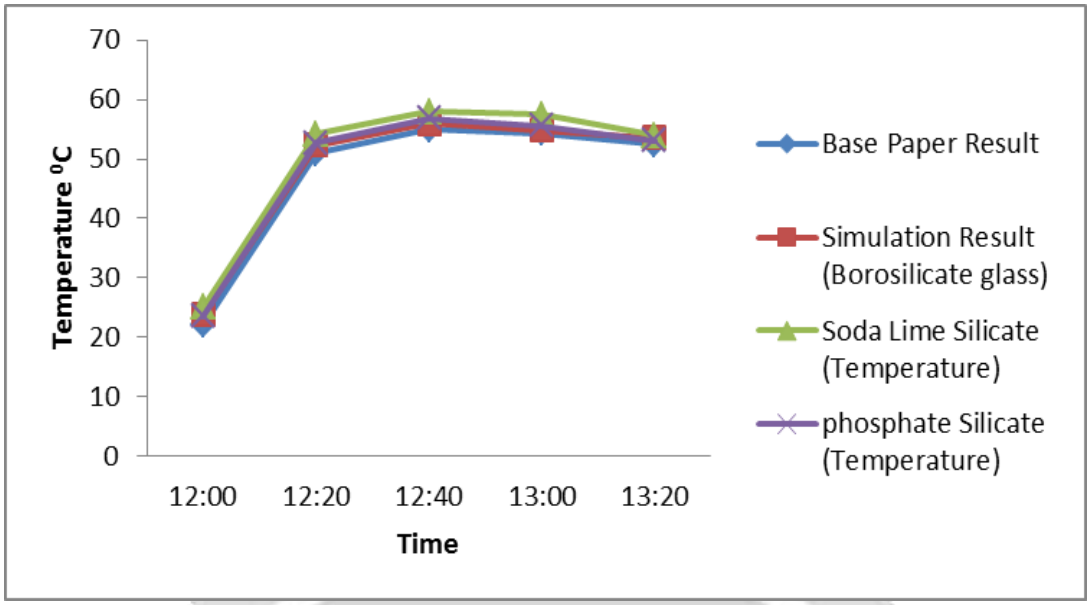

Figure: 6.3 Variation in temperature on heat pipe wr.t. time

VII CONCLUSION

1. Computational model has been developed in UGNX 8.0 and analysis has been done in Fluent 15.0.
2. Numerical results are in good agreement with base paper results.
3. The internal consistency of the results confirms the validity of the CFD model.
4. From results, higher value of temperature is found out for different glass materials of heat pipe.
5. Soda lime silicate with copper pipe material shows more convergence than other glass materials of heat pipe (heater zone) thus result shows improvement of 6.8% average deviation on temperature.
6. Temperature distribution shows 0.73% average on simulation results than base paper results thus convergence on temperature effect is achieved.
7. Thus numerical simulation of heat pipe with respect to different glass materials with copper pipe shows an optimum result on both temperature and mass transfer.
8. From results, higher temperature drop is found out for Hexacosane Nano fluid comparison to different Nano fluid of heat pipe.

.References

1)Alexios Papadimitratos, Sarvenaz Sobhansarbandi, Vladimir Pozdin Anvar Zakhidov, Fatemeh Hassanipour, "Evacuated tube solar collectors integrated with phase change materials," Solar Energy 129 (2016) 10–19

2)M.S. Abd-Elhady M. Nasreldin, M.N. Elsheikh, "Improving the performance of evacuated tube heat pipe collectors using oil and foamed metals," Ain Shams Engineering Journal xxx (2017) xxx–xxx.

3)Sarvenaz Sobhansarbandi, Patricia M. Martinez, Alexios Papadimitratos, Anvar Zakhidov, Fatemeh Hassanipour, "Evacuated tube solar collector with multifunctional absorber layers," Solar Energy 146 (2017) 342–350.

4)S. Siva Kumara, K. Mohan Kumarb, S. R Sanjeev Kumarc, "Design of Evacuated Tube Solar Collector with Heat Pipe" Materials Today: Proceedings 4 (2017) 12641–12646.

5)A.E. Kabeel, Mohamed M. Khairat Dawood, Ali I. Shehata, "Augmentation of thermal efficiency of the glass evacuated solar tube collector with coaxial heat pipe with different refrigerants and filling ratio," Energy Conversion and Management 138 (2017) 286–298.

6)Piotr Felinski and Robert Sekret, "Effect of a low cost parabolic reflector on the charging efficiency of an evacuated tube collector/storage system with a PCM," Solar Energy 144 (2017) 758–766.

7)Meysam Faegh, Mohammad Behshad Shafii, "Experimental investigation of a solar still equipped with an external heat storage system using phase change materials and heat pipes," Desalination 409 (2017) 128–135

8)Mohamed Hany Abokersh, Mohamed El-Morsi, Osama Sharaf, Wael Abdelrahman "On-demand operation of a compact solar water heater based on U-pipe evacuated tube solar collector combined with phase change material," Solar Energy 155 (2017) 1130–1147.

9)Saıf ed-Dın Fertahi, T. Bouhal A. Arid, T. Kousksou , A. Jamil , N. Moujibi, A. Benbassou, "Thermo-mechanical strength analysis for energy storage improvement of horizontal storage tanks integrating evacuated tube collectors," i n t e r n a t i o n a l journal of hydrogen energy xxx (2 0 1 7) 1 -11.

10)Vahit Corumlu, Ahmet Ozsoy, Murat Ozturk, "Thermodynamic studies of a novel heat pipe evacuated tube solar collectors based integrated process for hydrogen production," i n t e r n a t i o n a l journal of hydrogen energy xxx (2 0 1 7) 1 -1 1.

11)Guillermo Martínez-Rodríguez, Amanda L. Fuentes-Silva and Martín Picón-Núñez, "Solar Thermal Networks Operating with Evacuated-Tube collectors," 10.1016/j.energy.2017.04.165.

12)Tahmineh Sokhansefata, Alibakhsh Kasaeiana, Kiana Rahmania, Ameneh Haji Heidarib, Faezeh Aghakhanic , Omid Mahiand, "Thermoeconomic and Environmental Analysis of Solar Flat Plate and Evacuated Tube Collectors in Cold Climatic Conditions" 10.1016/j.renene.2017.08.057.

13)Amir Amini, Jeremy Miller, Hussam Jouhara, "An investigation into the use of the heat pipe technology in thermal energy storage heat exchangers" Energy xxx (2016) 1e10.

14)Pooria Behnam, Mohammad Behshad Shafii, "Examination of a solar desalination system equipped with an air bubble column humidifier, evacuated tube collectors and thermosyphon heat pipes" Desalination 397 (2016) 30–37.

15)Roonak Daghigh, Abdellah Shafieian, "An experimental study of a heat pipe evacuated tube solar dryer with heat recovery system," Renewable Energy 96 (2016) 872-880.

16)P. Felinski, R. Sekret, "Experimental study of evacuated tube collector/storage system containing paraffin as a PCM, Energy 114 (2016) 1063-1072.

17)Debabrata Pradhan, Debrudra Mitra, Subhasis Neogi, "Thermal Performance of a Heat Pipe Embedded Evacuated Tube Collector in a Compound Parabolic Concentrator," Energy Procedia 90 (2016) 217 – 226.

18)M.S. Naghavi, K.S. Ong, I.A. Badruddin, M. Mehrali, M. Silakhori, H.S.C. Metselaar "Theoretical model of an evacuated tube heat pipe solar collector integrated with phase change material," Energy 91 (2015) 911-924.

19)M.A.Sabiha, R.Saidur, SaadMekhilef, Omid Mahian, "Progress and latest developments of evacuated tube solar collectors," Renewable and Sustainable Energy Reviews 51 (2015) 1038–1054.

20)P.Selvakumar, P.Somasundaram, P.Thangave, An Experimental Study on Evacuated Tube Solar Collector using Therminol D-12 as Heat Transfer Fluid Coupled with Parabolic Trough, International Journal of Engineering and Technology (IJET) ISSN : 0975-4024 Vol 6 No 1 Feb-Mar 2014

21)C. A. Papadopoulos and A. D. Dimarogonas, "Coupling of bending and torsional vibration of a cracked Timoshenko shaft," Ingenieur-Archiv, vol. 57, no. 4, pp. 257–266, 1987.

22)A. S. Sekhar and B. S. Prabhu, "Vibration and stress fluctuation in cracked shafts," Journal of Sound and Vibration, vol. 169, no. 5, pp. 655–667, 1994.

23)B. O. Dirr, K. Popp, and W. Rothkegel, "Detection and simulation of small transverse cracks in rotating shafts," Archive of Applied Mechanics, vol. 64, no. 3, pp. 206–222, 1994.

24)M. A. Mohiuddin and Y. A. Khulief, "Modal characteristics of cracked rotors using a conical shaft finite element," Computer Methods in Applied Mechanics and Engineering, vol. 162, no. 1–4, pp. 223–247, 1998.

25)A. S. Sekhar and P. Balaji Prasad, "Dynamic analysis of a rotor system considering a slant crack in the shaft," Journal of Sound and Vibration, vol. 208, no. 3, pp. 457–473, 1997.

26)A. S. Sekhar, "Vibration characteristics of a cracked rotor with two open cracks," Journal of Sound and Vibration, vol. 223, no. 4, pp. 497–512, 1999.

27)A. Nandi, "Reduction of finite element equations for a rotor model on non-isotropic spring support in a rotating frame," Finite Elements in Analysis and Design, vol. 40, no. 9-10, pp. 935–952, 2004.

28)A. K. Darpe, "Dynamics of a Jeffcott rotor with slant crack," Journal of Sound and Vibration, vol. 303, no. 1-2, pp. 1–28, 2007.

29)N. Bachschmid and E. Tanzi, "Deflections and strains in cracked shafts due to rotating loads: a numerical and experimental analysis," International Journal of Rotating Machinery, vol. 10, pp. 283–291, 2004.

30)Huichun Peng, Qing He, Pengcheng Zhai, Yaxin Zhen, "Stability analysis of an open cracked rotor with the anisotropic rotational damping in rotating operation", Elsevier 2017.

31)R. Tamrakar and N. D. Mittal, "Campbell diagram analysis of open cracked rotor", Engineering Solid Mechanics Growing Science 2016.

32)Zhiwei Huang et al, "Dynamic analysis on rotor-bearing system with coupling faults of crack and rub-impact", MOVIC 2016 & RASD 2016.

33)Anuj Kumar Jain, Vikas Rastogi, Atul Kumar Agrawal, "Experimental Investigation of Vibration Analysis of Multi-Crack Rotor Shaft", Science Direct 2016.

34)M. Serier, A. Lousdad, K. Refassi, A. Megueni, "Analysis of Parameters Effects on Crack Breathing and Propagation in Shaft of Rotor Dynamic Systems", Material Research 2013.

35)Sri Raghava M., G. Diwakar, P. Madhu Kumar, "Vibration Analysis of Cracked Rotor Using Numerical Approach", IOSR-JMCE 2013.

36)Guangming Dong, Jin Chen, "Vibration analysis and crack identification of a rotor with open cracks", Japan Journal of Industrial Applied Mathematics 2011.

37)Al-Jandal, S., Sayigh, A., 1994. Thermal performance characteristics of stc system with phase change storage. Renew. Energy 5, 390–399.

38)Bansal, N., Buddhi, D., 1992. An analytical study of a latent heat storage system in a cylinder. Energy Convers. Manage. 33, 235–242.

39)Boy, E., Boss, R., Lutz, M., 1987. A collector storage module-with integrated phase change material. Proc. ISES. Pergamon Press, Hamburg, pp. 3672–3680.

40)Browne, M.C., Lawlor, K., Kelly, A., Norton, B., Mc Cormack, S.J., 2015. Indoor characterisation of a photovoltaic/thermal phase change material system. Energy Proc. 70, 163–171.