

Numerical modelling of Heat Pipe for enhancement of overall performance by variable working fluid and different glass material

Apsad Ali^{1*}, Dr Rahul Kumar Singh²

^{1*,2}Rabindranath Tagore University Bhopal, Madhya Pradesh apsad_ali@yahoo.co.in; rahulkumarsingh77@gmail.com

ABSTRACT

This article uses several glass heat pipe types with varied profiles, meaning that simulations were run at different temperatures with respect to time. A higher temperature value is obtained by simulating an evacuated glass tube filled with soda lime silicate. The CAD model of the heat pipe used in this study was created with ANSYS. In order to observe different parameters impacting the heat pipe's performance in terms of thermal and phase transformation, the model has been simulated using ANSYS software on a fluent domain workbench. Additionally, it has been noted that, in comparison to earlier configurations, the 10 mm wall thickness of the copper pipe material engaged with the glass material exhibits greater convergence at the soda lime silicate glass evacuated tube. The outcomes are verified against the published base paper results. Among all the configurations tested, the soda lime silicate glass material configuration yields the highest convergence on all parameters when the fluid flow (octadecane) Nanofluid is placed within a heat pipe. We discovered that they provide superior mass transformation and temperature dispersion in the heat pipe's capillary tube. According to our investigation, the temperature of the erythritol nanofluid in the soda lime silicate glass evacuated tube in the heat pipe is greater.

Keyword: - Heat pipe, Temperature, Borosilicate, soda lime silicate, copper pipe, octadecane, Erythritol, Silicon oil.

1 INTRODUCTION

In recent years, a number of theoretical and practical configurations of solar water heater (SWH) systems integrated with phase change material (PCM) called LHTES (latent heat thermal energy storage) have been created and evaluated [1–9]. The PCM was inserted into the hot water storage tank as a spherical or cylindrical packed bed portion in the majority of the designs [10–13]. To obtain the performance at various incident angles, one method is to use an incidence angle modifier (IAM) [14]. A standalone point-focus parabolic solar still's performance was experimentally assessed, and a maximum production of 5.12 kg/day was attained. On the other hand, they found no evidence of a substantial impact of water salinity, wind speed, or air temperature on production [15]. [16] used the method of injecting air into hot water in an HDH process to assess the system's productivity. This method employed compressors to force air into the water and electrical heaters to heat the water. The quoted cost of desalinated water was rather high because of the compressor's high cost and the amount of power it used. The impact of employing a direct contact bubbling humidification technique on an HDH process's output rate was examined by Ghazal et al. [17]. In this setup, a compressor forces air into the water within the solar collector. The output air of a solar collector was found to be saturated, and the use of a reflector mirror raised the absolute humidity by 32%. A recent experimental research on a solar HDH system using an air bubble column humidifier was conducted by Khalil et al. [18]. The effects of air flowrate, water temperature, and the hole diameter of the sieve on the system's performance were examined. It was demonstrated that the daily effectiveness was 63%. The performance of air bubble column humidifiers was found to be superior to that of traditional humidifier systems. It is desired that solar energy be used in these systems to minimize energy consumption, given the low operating temperature of HDH processes. A variety of solar collectors or photovoltaic panels were employed in several earlier investigations to provide the necessary energy for the HDH processes' air or water heating. In an experimental study, Zamen et al. [19] investigated a two-stage solar HDH system that heated water using flat plate collectors. When the intended system was tested in both warm and cold weather conditions throughout the year, it was discovered that the daily production of fresh water in the winter was significantly lower than that of fresh water in the summer. It was demonstrated that the weather has a major impact on the performance of typical flat plate collectors; as a result, their efficiency was greatly decreased on gloomy and chilly days. Compared to flat plate collectors, evacuated tube collectors work better because they have the two benefits of evacuated space and correct shape. These collectors perform better thermally at higher temperatures because convection and conduction losses are less as a result of the evacuated space inside of them. In the meanwhile, a heat pipe in the evacuated tube collector may transmit a sizable quantity of heat from the heat source to the heat sink since it is an extremely effective thermal conductor. An evacuated tube that has been filled with the appropriate volume of working fluid is called a heat pipe. The impact of utilizing various working fluids on the performance of heat pipes has been the subject of several research [20, 21]. Kumar et al. studied the design, development, and performance assessment of many kinds of solar dryers [22]. In their study, the physical attributes of various solar dryers as well as a technoeconomic analysis were given. Chauhan and colleagues [23] have examined the use of software in sun drying systems. The study stressed how crucial it is to employ software when creating and evaluating the mathematical models that are used to forecast how well various types of sun drying systems would work. Rittidech et al.'s study [24] looked on using heat pipes directly in dryers. For energy efficiency in a dryer, closed-ended oscillating heat pipes

were employed as an air preheater. The suitability of the heat pipe airpreheater as a heat recovery device was investigated and an experimental prototype was developed and constructed.

1.1 Problem Identification

The survey of different previous works used in Borosilicate glass materials in evacuated tube. We found that low heat transfer rate, low thermal diffusivity and thermal conductivity in previous survey, further analysis is done by optimizing the evacuated glass material and change the Nanofluid of heat pipe with hexacosane, silicon oil, erythritol.

Table 1: Previous and present configurations of heat pipe.

Debabrata Pradhan et.al. [25] - Heat pipe Length 1800 mm - Material Copper - - Evaporator length- 1700 mm - Evaporator diameter - 6 mm - Condenser length- 100 mm - Condenser diameter- 10 mm - Evacuated tube length -1780 mm - Outer tube diameter- 58 mm - Inner tube diameter- 52 mm	M.S. Naghavi et.al. [26] - Distance between fins on shell- 12 - Pipe outer diameter -13 - Fin height on pipe -9 - Fin thickness on pipe - 0.5 - Fins pitch on pipe- 5	P. Selvakumar et.al. [27] Heat pipe 100 mm of evaporator section. 80 mm of adiabatic section. 150 mm of condenser section.
Present Configuration		
S.No.	Dimensional Parameters	Dimensions
1	Parabola length	1.5m
2	Parabola width	1m
3	Parabola depth	0.4m
4	Focal height	0.15m
5	Evacuated tube outer diameter	0.05m
6	Evacuated tube length	1.5m
7	Capillary diameter	0.03m

1.2 Analysis step

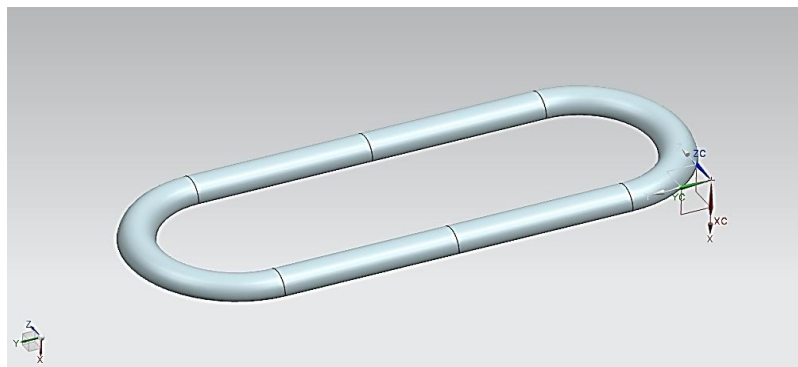


Fig 1. CAD model of heat pipe.

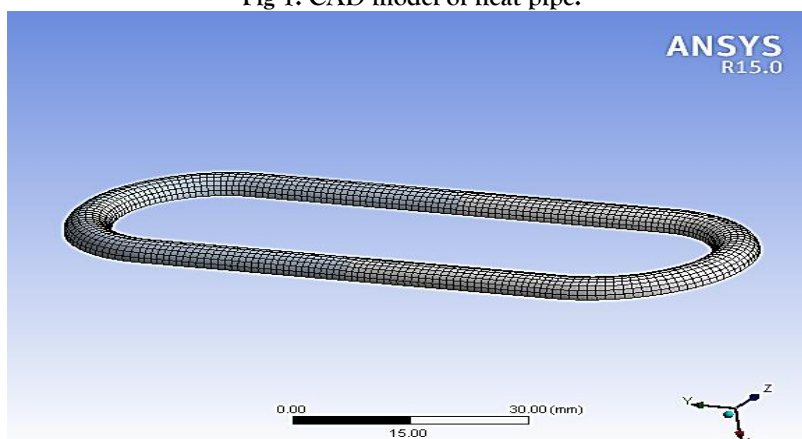


Figure 2. Meshed domain of heat pipe.

Fluent setup:

After mesh setup generation define the following steps in the ANSYS fluent 15.0

- Problem type – 3D solid
- Type of solver – pressure
- Physical model – viscous K-epsilon two equation turbulence model
- Mixture - volume of fraction

Solution Method

- Pressure – Velocity – Coupling – Scheme – Simple
- Pressure – standard pressure
- Momentum – 2nd order
- Turbulence – kinetic energy 2nd order
- Turbulence dissipation rate 2nd order

1.3 Boundary conditions

Heater Section (Evaporation section)	Temperature is defined
Adiabatic Zone (Phase transformation Section)	Conduction is defined
Condensation zone	Convection is defined
Wall of Capillary	Considered with different glass material

1.4 Material Properties

Table 2: Materials Properties

Properties	Borosilicate glass	Soda lime silicate glass	Phospho Silicate Glass
Density, ρ	2230 Kg/m ³	2530Kg/m ³	2585 Kg/m ³
Thermal Conductivity, K	1.14 W/m-K	0.937 W/m-K	0.57 W/m-K
Specific Heat, Cp	830J/Kg-K	720 J/Kg-K	632J/Kg-K

Table 3.2 Properties of Nano-Fluids

Nano-Fluids	Density	viscosity	Thermal Conductivity	Boiling Point
Octadecane	0.777	-	0.153 W m ⁻¹ K ⁻¹	317 °C (603 °F; 590 K)
Silicon Oil	0.971 g/mL at 25 °C	10,000 cSt(25 °C)	0.6 W/m/K	>140 °C/0.002 mmHg (lit.)
Hexacosane	0.8±0.1 g/cm ³		0.23 W/ mK	412.2±8.0 °C at 760 mmHg
Erythritol	1.45 g/cm ³		0.733W m ⁻¹ K ⁻¹	329 to 331 °C (624 to 628 °F; 602 to 604 K)

Table 3: Temperature distribution on heat pipe with same configuration (Validation)

Base Paper Result	Time
22	12:00
51	12:20
55	12:40
54.3	13:00
52.5	13:20

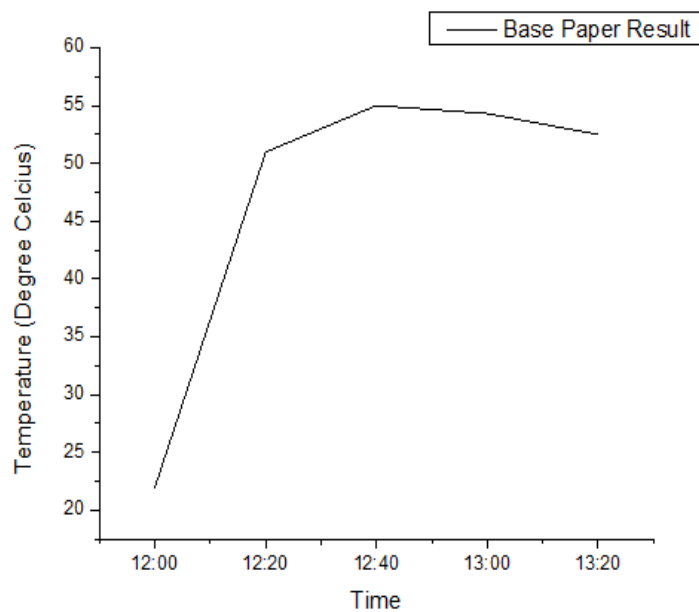


Figure 3. Base paper results and Simulation Results of variation in temperature for the heat pipe w.r.t. Time.

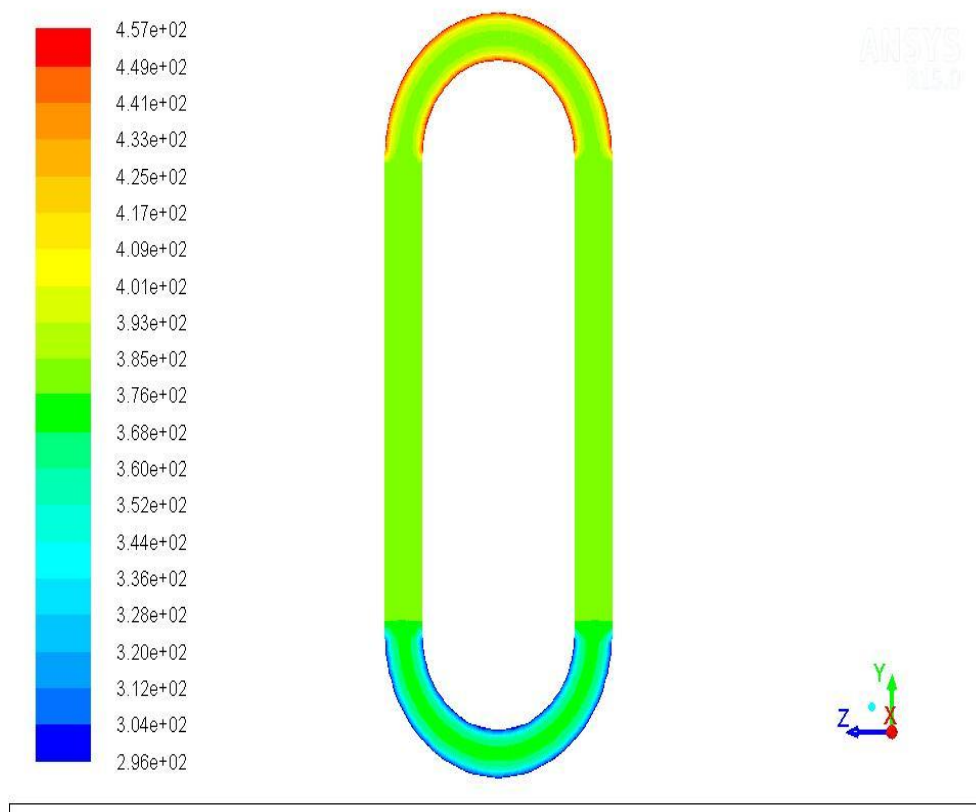


Figure 4. Temperature variation in heat pipe on 12:20.

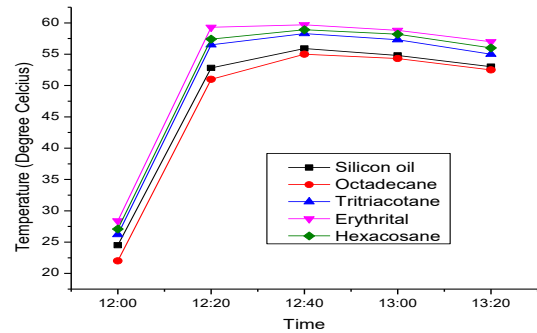


Figure 5. Overall comparison of variation in Temperature for different nanofluid with the heat pipe with respect to Time.

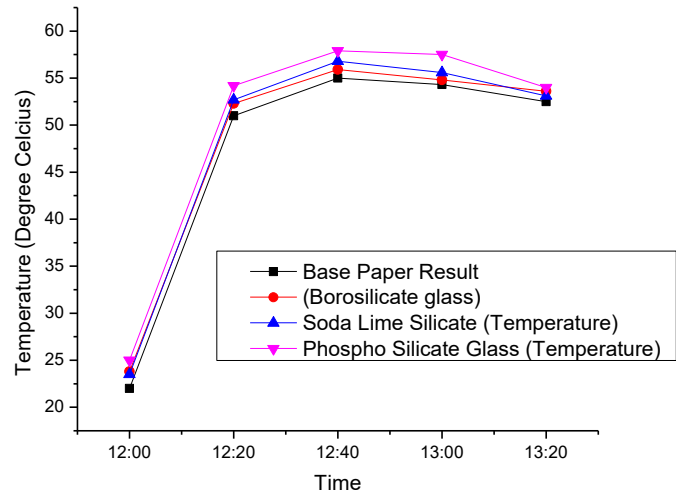


Figure 6. Variation in temperature on heat pipe w.r.t. time and different glass material.

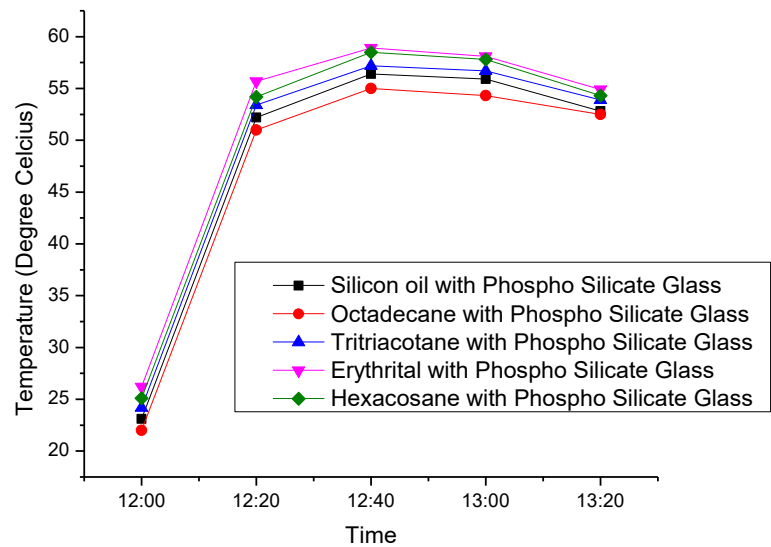


Figure 7. Overall comparison of variation in Temperature for different nanofluid with the phosphor silicate glass material heat pipe with respect to Time.

CONCLUSION

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. Temperature distribution shows 0.73% average on simulation results than base paper results thus convergence on temperature effect is achieved. 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. From results, higher temperature drop is found out for Erythritol Nanofluid comparison to different Nanofluid of heat pipe. Our analysis found Erythritol nanofluid are higher temperature in soda lime silicate glass evacuated tube in heat pipe. The combination of sodalime silicate glass with Erythritol imposes optimum configuration in temperature distribution also this combination is economical.

REFERENCES

- [1] Mazman M, Cabeza LF, Mehling H, Nogues M, Evliya H, Paksoy H. Utilization of phase change materials in solar domestic hot water systems. *Renew Energy* 2009;34(6):1639-43.
- [2] Wu S, Fang G. Dynamic performances of solar heat storage system with packed bed using myristic acid as phase change material. *Energy Build* 2011;43(5):1091-6.
- [3] Koca A, Oztup HF, Koyun T, Varol Y. Energy and exergy analysis of a latent heat storage system with phase change material for a solar collector. *Renew Energy* 2008;33(4):567-74.
- [4] Malvi CS, Dixon-Hardy DW, Crook R. Energy balance model of combined photovoltaic solar-thermal system incorporating phase change material. *Sol Energy* 2011;85(7):1440-6.
- [5] Varol Y, Koca A, Oztup HF, Avci E. Forecasting of thermal energy storage performance of phase change material in a solar collector using soft computing techniques. *Expert Syst Appl* 2010;37(4):2724-32.
- [6] Kousksou T, Buel P, Cherreau G, Leoussoff V, El Rhafiki T. PCM storage for solar DHW: from an unfulfilled promise to a real benefit. *Sol Energy* 2011;85(9):2033-40.
- [7] Benli H, Durmus A. Performance analysis of a latent heat storage system with phase change material for new designed solar collectors in greenhouse heating. *Sol Energy* 2009;83(12):2109-19.
- [8] Eames PC, Griffiths PW. Thermal behaviour of integrated solar collector/ storage unit with 65_C phase change material. *Energy Convers Manag* 2006;47(20):3611-8.
- [9] Saman W, Bruno F, Halawa E. Thermal performance of PCM thermal storage unit for a roof integrated solar heating system. *Sol Energy* 2005;78(2):341-9.
- [10] Nallusamy N, Sampath S, Velraj R. Experimental investigation on a combined sensible and latent heat storage system integrated with constant/varying (solar) heat sources. *Renew Energy* 2007;32(7):1206-27.
- [11] Khalifa AJN, Suffer KH, Mahmoud MS. A storage domestic solar hot water system with a back layer of phase change material. *Exp Therm Fluid Sci* 2013;44(0):174-81.
- [12] Al-Hinti I, Al-Ghandoor A, Maaly A, Abu Naqeera I, Al-Khateeb Z, Al-Sheikh O. Experimental investigation on the use of water-phase change material storage in conventional solar water heating systems. *Energy Convers Manag* 2010;51(8):1735-40.
- [13] Ib_a~nez M, Cabeza LF, Sol_e C, Roca J, Nogu_es M. Modelization of a water tank including a PCM module. *Appl Therm Eng* 2006;26(11-12):1328-33.
- [14] Shah LJ, Furbo S. Vertical evacuated tubular-collectors utilizing solar radiation from all directions. *Appl Energy* 2004;78:371-95.
- [15] Gorjian S, Ghobadian B, Hashjin TT, Banakar A. Experimental performance evaluation of a stand-alone point-focus parabolic solar still. *Desalination* 2014; 352:1-17.
- [16] S.A. El-Agouz, Desalination based on humidification-dehumidification by air bubbles passing through brackish water, *Chem. Eng. J.* 165 (12/1/2010) 413-419, <http://dx.doi.org/10.1016/j.cej.2010.09.008>.
- [17] M.T. Ghazal, U. Arikol, F. Egelioglu, An experimental study of a solar humidifier for HDD systems, *Energy Convers. Manag.* 82 (6/2014) 250-258, <http://dx.doi.org/10.1016/j.enconman.2014.03.019>.
- [18] A. Khalil, S.A. El-Agouz, Y.A.F. El-Samadony, A. Abdo, Solar water desalination using an air bubble column humidifier, *Desalination* 372 (9/15/2015) 7-16, <http://dx.doi.org/10.1016/j.desal.2015.06.010>.
- [19] M. Zamen, S.M. Soufari, S.A. Vahdat, M. Amidpour, M.A. Zeinali, H. Izanloo, et al., Experimental investigation of a two-stage solar humidification-dehumidification desalination process, *Desalination* 332 (1/2/2014) 1-6, <http://dx.doi.org/10.1016/j.desal.2013.10.018>.
- [20] M. Arab, A. Abbas, A model-based approach for analysis of working fluids in heat pipes, *Appl. Therm. Eng.* 73 (12/5/2014) 751-763, <http://dx.doi.org/10.1016/j.applthermaleng.2014.08.001>.
- [21] M. Arab, A. Abbas, Model-based design and analysis of heat pipe working fluid for optimal performance in a concentric evacuated tube solar water heater, *Sol. Energy* 94 (8/2013) 162-176, <http://dx.doi.org/10.1016/j.solener.2013.03.029>.
- [22] M. Kumar, S.K. Sansaniwal, P. Khatak, Progress in solar dryers for drying various commodities, *Renew. Sustain. Energy Rev.* 55 (2016) 346-360.
- [23] P. Chuchan, A. Kumar, P. Tekasakul, Applications of software in solar drying systems: a review, *Renew. Sustain. Energy Rev.* 51 (2015) 1326-1337.
- [24] S. Rittidech, W. Dangeton, S. Soponronnarit, Closed-ended oscillating heatpipe (CEOHP) air-preheater for energy thrift in a dryer, *Appl. Energy* 81 (2) (2005) 198-208.
- [25] Debabrata Pradhan, Debrudra Mitra, Subhasis Neogi, Thermal Performance of a Heat Pipe Embedded Evacuated Tube Collector in a Compound Parabolic Concentrator, Volume 90, December 2016, Pages 217-226.