Volume 3, Issue 3 (2015) 498-502 ISSN 2347 - 3258
International Journal of Advance Research and Innovation

Thermodynamic Analysis of Heat Pipe Using Ammonia, Water and Ethanol with a View to Being Used in Refrigeration

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Article Info

Article history:
Received 10 July 2015
Received in revised form
20 July 2015
Accepted 28 August 2015
Available online 15 September 2015

Keywords

Ammonia,
Ethanol,
Heat Pipe

Abstract

Heat pipe was developed by NASA for space applications, and this device can be used in simple refrigeration systems, which will have a great impact on the size of the system. Several working fluids can be used in the heat pipe along with the different available material in the designs of the pipe. In this research work several parameters of a heat pipe are observed varying the design conditions alongside the working fluid in the heat pipe which are Water, Ammonia and Ethanol analysed on software. The design conditions are kept as it would be in a commonly used refrigeration system. The capacity of the system is varied and analysis is done. The capacity can be enhanced without much change in the size. Also the temperature of working becomes more or less constant. Water turns out to be a very effective working fluid in a heat pipe with the view of refrigeration when the temperature of working increases.

1. Introduction: Heat Pipes

1.1 History

Heat Pipes were developed particularly for space applications ' by the NASA. One principle problem in space applications was to transport the heat from inside to the outside, on the grounds that the heat conduction in a vacuum is exceptionally restricted. So there was a need to create a quick and viable approach to transport heat, without having the impact of gravity. The thought behind is to make a flow field which transports heat from one spot then onto the next by mode of convection, in light of the fact that convective heat exchange is much quicker than conduction. These days, heat pipes are utilized in many applications, where one has restricted space and the need of a high heat flux. Obviously, it is still being used in space applications, yet it is likewise utilized as a part of heat exchange systems, cooling of PCs, cell telephones and cooling of solar based collectors.

1.2 Principle of Working

The fundamental of heat pipes is dependent of evaporation and condensation. At the hot side, the working liquid is evaporated and at the cool side it condenses. As every material has different properties, it's required to choose the set of material properly. At the source the cool fluid is evaporated, the hot vapour stream is a while later transported to the sink where the vapour condenses again and is transported back to the source. The issue of this procedure is the space utilization; consequently it was important to build up a compacter approach to transport heat with the indicated procedure. The thought of a Heat Pipe is presently to incorporate the complete convective transport in one channel, where the vapour stream is in the centre of the pipe and the floe happens to be on the outside of the barrel. Heat exchange is so efficient that fundamentally it is a direct result of the low heat resistance because of the convective stream, as explained earlier. This low heat resistance is because of little effective length of heat exchange through strong porous wick walls.

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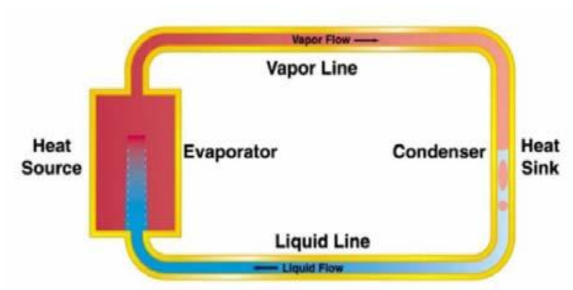

Fig: 1. Circular Process of a Heat Pipe [2]

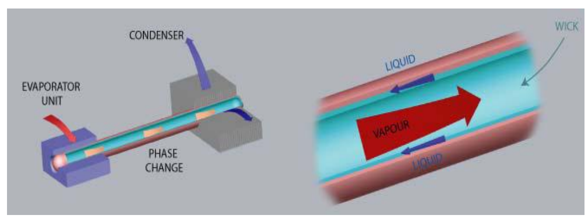

Fig: 2. Concept of Heat Pipe [2]

1.3 Key Features of Heat Pipe

- Very high heat transfer capacity in a simple system.
- Allows several Heat Transport passes, avoids a single point breakdown.
- Smaller units, no bulky pressure vessel.
- Valves, pumps or compressors are not required.
- Can be started cold, no need of preheat.
- High temperatures allow very high efficiency operation, almost constant temperature process.

1.4 The Selection of the Working fluid in the Heat Pipe

The Fluids used in the Heat Pipe are chosen on the basis of their merit:

1. Water
2. Ammonia
3. Ethanol

Also these fluids are very easily available. These also show the best Figure of Merit to be used in heat pipe applications. These fluids are cheap and non toxic in nature. Ethanol is flammable so it's used must be strictly observed.

The latent heat of vaporisation and condensation is also a very big deciding factor for the fluid in heat pipe. The working liquid must have great thermo-physical properties at the predetermined operational temperature and weight. Working liquid must have high wettability, surface tension and other attractive thermo-physical properties incorporating a high fluid thermal conductivity, high inert enthalpy of vaporization, low fluid viscosity, and a low vapour viscosity.

1.5 Limitations

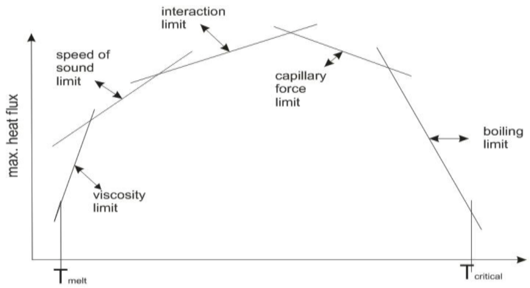

Fig: 3. Limitations of a Heat Pipe [2]

- **Melting Temperature:** One can't utilize a heat pipe below the melting temperature.
- **Viscosity Limit:** The viscosity of the liquid is too high for being transported at low temperatures and low pressures.
- **Sonic Limit:** It is critical for high temperature, where the vapour could conceivably achieve the velocity of sound while leaving the source.
- **Capillary limit:** When the capillary force is definitely not fulfilling the required force transport the fluid
- **Interaction limit:** This breaking point is associated with open channels, where the vapour can be diverted by the vapour, because of high speed contacts.
- **Boiling cut off:** The fluid forms bubbles which close the capillaries, it's not an issue for open channel structures
- **Critical temperature:** Beyond the critical temperature the concept of vapour and liquid seizes to exist.

2. Literature Review

P. Yeunyongkul et al.[2010] conducted set of experiments for which the results of closed loop oscillating heat pipe (CLOHP) condenser was connected to vapor compression refrigeration. In which two cons of split sort ventilation system were considered [1]. ***Fabian Korn et al. [2012]*** performed several vital experiments on heat pipes to establish it to be one of the most effective procedures to transport thermal energy from one point to another, mostly used for cooling [2]. ***Sameer Khandekar et al. [2010]*** performed experiments on the global thermal performance modeling of Pulsating Heat Pipes (PHPs) requires local, spati-o-temporally coupled, flow and heat transfer information during the characteristic, self-sustained thermally driven oscillating Taylor bubble flow, under different operating conditions[3]. ***Jozef Hužvár, Patrik Nemec et al. [2007]*** used heat pipe, observed its basic principles and operating limits. High temperature heat pipes were evaluated for use in energy conversion applications such as fuel cells, gas turbine re-combustors, and Stirling cycle heat sources, with the resurgence of space nuclear power, additional applications include reactor heat removal elements and radiator elements [4]. ***R.Z. Wanget al. [2008]*** added heat pipes in adsorption water chiller or ice maker initials. His work showed that the adsorption refrigerators are very efficient [5]. ***Pracha Yeunyongkul et al.[2009]*** aimed at experimentally investigating the application of a closed loop oscillating heat pipe (CLOHP) as the condenser for a vapor compression refrigeration system[6]. ***R. Rajashree et al. [1990]*** went through a numerical analysis of an unsteady, viscous, laminar, incompressible, two dimensional heat and mass transfer, in the vapour gas region of gas loaded circular heat pipe [7].

In the case of heat pipe an analysis based on multiple easily available working fluid, with different working conditions can be done. For an example liquid Sodium is not a vital fluid to be used for common refrigerating plants, where fluids as methanol, ethanol, water ammonia etc can make the use of heat pipe in the main stream. Also the main parameters of a heat pipe such as cross-sectional area of the wick, Heat Transfer Factor etc can be analysed on the basis of varying design variables such as operating temperature, pore radius, wick permeability, wick material, maximum heat to be transported etc. Along with being used in the VCR system it can be used in an ejector type refrigerating unit and vapour absorption and Electrolux and may enhance the performance of these systems. In the case of observing the changes brought by a regenerative heat exchanger and a flash gas removing chamber along with two stage compression without inter-cooling with eco-friendly refrigerants a comparison with Simple VCR cycle can be observed and same for the VARS cycle can be done.

3. Systems Description

The system has to have a capacity of 10 TR increasing up to 50 TR at the evaporator temperature also the evaporator temperature will be observed from 253K to 273K. Considering the surrounding situation of the country the condenser temperature will be varied from 313K to 328K.In the study the condenser used in the VCRS will be replaced by a Heat pipe of a chosen wick material 30 mesh screens. The effect of the size change will be observed with the application of heat pipe. Also three different fluids for heat pipe namely Water, Ammonia and Ethanol will be checked for their merits and what effect would they have on the design of heat pipe. The heat taken by the condenser will now be absorbed by the heat pipe and a direct comparison for the size of these two components would be sought after. The length of tubes in the evaporator and condenser and the effective length of the heat pipe are kept 1 meter in length. A software analysis is done.

4. Performance Parameters

Figure of Merit (MF_h): The figure of merit is the ratio of the product of density, surface tension and latent heat of evaporation to the dynamic viscosity of the fluid at saturated liquid state. As it can be seen clearly the Figure of Merit is the ratio of the thermo-physical properties it is dependant only on the temperature of working. So its variation is observed with the variation of temperature between the working limits of the condenser of the system ie. 40 °C to 55 °C.

$MF_h = \rho_l \, \sigma \, h_{fg} / \mu_l$

Where:

ρ_l is the density of liquid in heat pipe in kg/m^3,

σ is the surface tension of the fluid in N/m,

h_{fg} is the latent heat of vaporization at heat pipe temperature in kJ/kg, and

μ_l is the viscosity of the liquid in Pa-s.

Maximum Heat transfer (Q_{max}) (Capillary Limitation): It's the maximum heat that can be transferred on the basis of capillary limitation.

$Q_{max} = (MF_h)(A_w k_{hp}/L_{eff})\{(2/r_p)-(\rho_l g \, L_{eff} \sin\phi / \sigma)\}$

where:

MF_h is the Figure of Merit in kW/m^2,

A_w is the cross sectional area of wick in m^2,

k_{hp} is the Permeability of the wick material in m^2,

L_{eff} is the effective length of the heat pipe in m,

r_p is the pore radius in m,

g is the acceleration due to gravity in m/s^2, and

Φ is the inclination angle in degrees.

Heat Transfer Factor: Heat transfer factor is another factor in the analysis which will affect the size of the heat pipe. It depends on permeability, pore radius, Figure of Merit and the wick area. Its unit is W-m, and plays an important in the designing of a heat pipe.

$HTF = (2 * MF_h * A_w * k_{hp}/r_p)$

The symbols have usual predefined meaning.

5. Results and Discussions

The analysis will show which one of the three fluids will work better at higher temperatures with a higher capacity of absorbing heat, with smallest size.

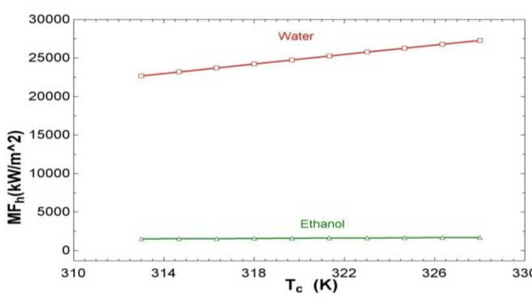

Fig: 4. Variation of Figure of Merit and Heat pipe temperature for Water and Ethanol [8]

Fig 4 shows a comparison between Figure of Merit and Heat pipe temperature for Water and Ethanol. The least Merit is related to the Ethanol while Water has substantially large value with rise in the temperature the figure of merit of water shows a rise while for ethanol it has a constant value.

In another analysis the variation in wick area (A_w) is observed with the operating temperature (T_c) and the Figure of Merit (MF_h).

The difference between the wick area required for Ethanol and Ammonia can be observed very easily, whereas the same required for Ammonia and water are comparable. Size is affected by the wick area required per unit effective length. Fig 5 and Fig 6 prove that with rise in temperature the wick cross-sectional area required is least for water as a working fluid.

The Refrigerating capacity is a very important parameter in any refrigeration plant. The capacity must be enhanced, size and the power consumption must be reduced to obtain a desired result. Hence the wick area with respect to the maximum heat absorbed by the heat pipe (Q_{max}) and the Refrigerating capacity is studied

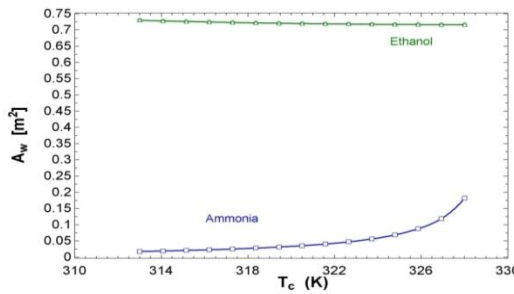

Fig: 5. Variation of Wick Area with operating temperature of heat pipe for Ethanol and Ammonia [8]

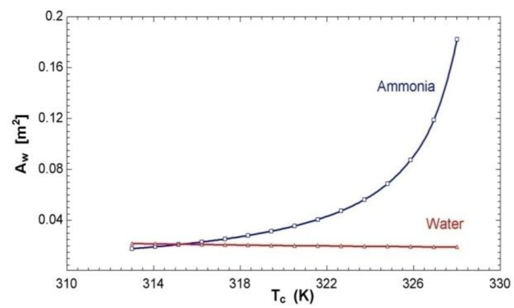

Fig: 6: Variation of Wick Area with operating temperature of heat pipe for Ammonia and Water [8]

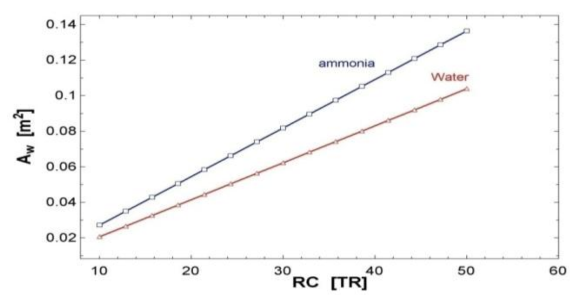

Fig: 7. Variation of Wick area with refrigerating capacity for Ammonia and Water [8]

The wick areas for Ammonia and Water are comparable and close enough. But water proves out to be better in this analysis. The separate variation for Ethanol is also shown.

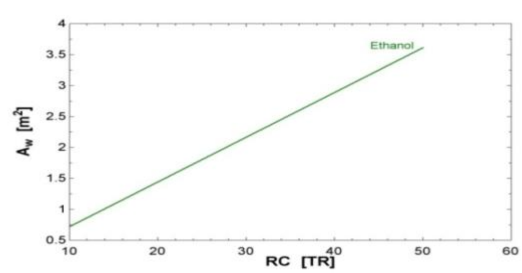

Fig: 8: Variation of Wick area with refrigerating capacity for Ethanol [8]

It is evident from Fig 7 and Fig 8 that water is giving a lesser area of heat pipe for the same capacity of the plant. The capacity can be increased and further analysis can be done.

Inclination angle of the heat pipe also affects the wick area required in the heat pipe. The inclination angle (ϕ) is measured in degrees. Variations obtained are as follows:

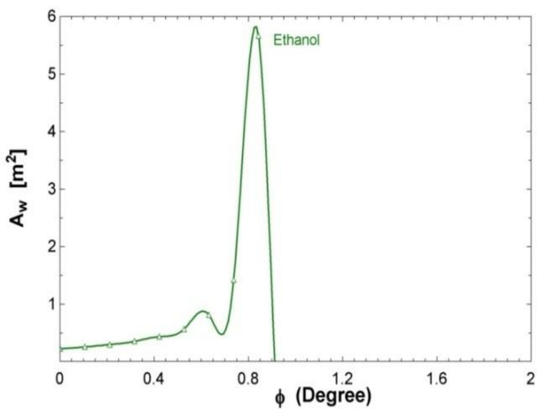

Fig: 9: Variation of Wick Area with Inclination Angle for Ethanol [8]

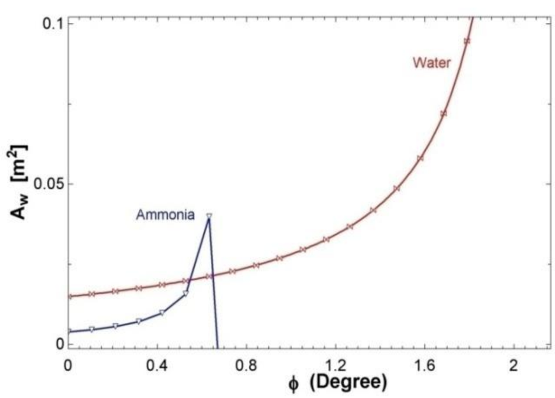

Fig: 10: Variation of Wick Area with Inclination Angle for Ammonia and Water [8]

Fig 9 and Fig 8 show the variation of the wick area with the inclination angle. It can be observed that as the inclination angle is increased area for water increases rapidly.

The plot for Water, Ammonia and Ethanol is obtained.

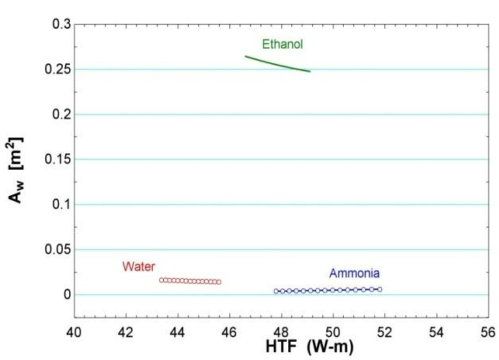

Fig: 11. Overlay Plot for Water, Ammonia and Ethanol [8]

Fig11 shows the variation of area with heat transfer factor .Area required for Ethanol is maximum and minimum with Ammonia. The Heat Transfer Factor is largest for the Ammonia and smallest for Water.

Another analysis is conducted to obtain the effect of pore radius r_p on the wick area. Parametric tables are presented as follows. The tables show respectively the relation between the A_w and r_p Water, Ammonia and Ethanol. The widest range of acceptable inclination angles is obtained for water, where as for ammonia area tends to negative for higher values of angle.

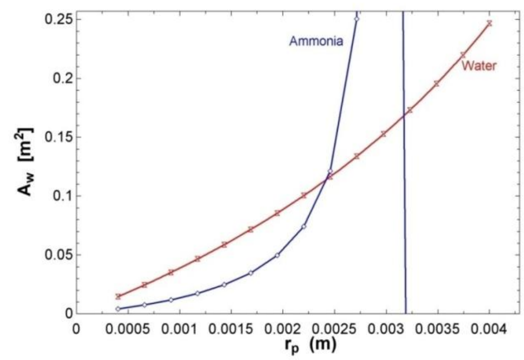

Fig: 12: Plot between Wick Area and Pore Radius for Ammonia and Water [8]

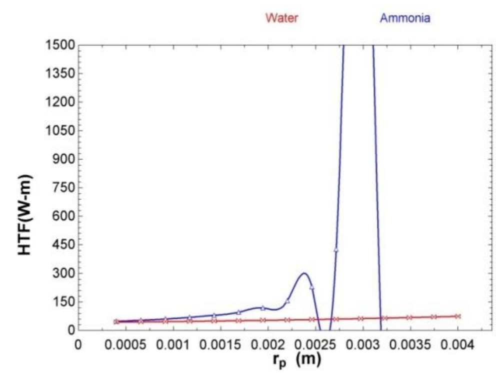

Fig: 13: Plot between HTF and Pore Radius for Ammonia and Water [8]

Fig: 12 shows the variation of wick cross-sectional area and pore radius with water and ammonia. For Water with increase in the pore radius the cross-sectional area goes on increasing but for Ammonia after a point it reduces. Fig 13 shows the variation of heat transfer factor and pore radius. For Water the heat transfer factor is more or less constant with the pore radius.

The heat pipe in this analysis replaces the conventional condenser which is deemed to be one of the essential parts of the refrigeration cycle. Be it a VCRS cycle or a VARS cycle condenser has always been there. The main advantage of a heat pipe is that it can be observed that its size will not be very huge even if the capacity of the system has to be enhanced. In this analysis Parametric Tables are prepared for condenser area, wick area, evaporator area with varying operating temperatures and refrigerating capacity and maximum heat transferred in heat pipe and condenser. The purpose is to show the difference in the condenser size, evaporator size and wick area of a heat pipe all the three having unit length.

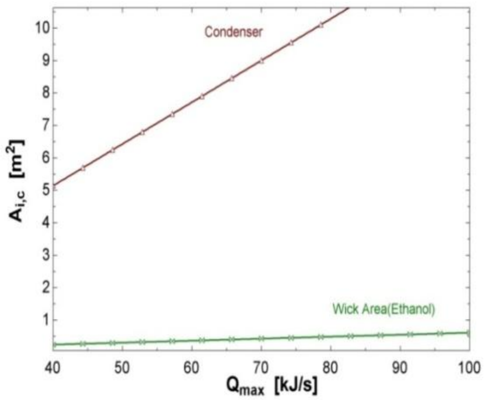

Fig: 14. Variation of Condenser area and wick area with heat capacity [8]

Fig 14 shows that the cross-sectional area of the wick is very small when compared to the heat transfer area of the condenser which result reduced size and capacity of the plant will also will be high.

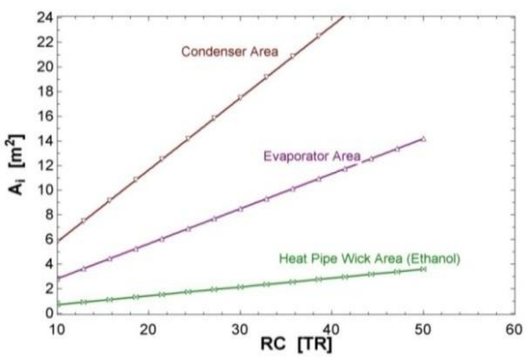

Fig: 15: Variation of condenser, evaporator and wick area with refrigerating capacity[8]

Fig: 15 shows the variation of areas of all the three heat exchangers that can be used in the system

6. Conclusions

From the results of the above research work the following conclusions can be made:

- The Figure of Merit of the working fluids Ammonia has the largest and Ethanol has the least merit. But Water shows the best possible results for the operating temperature of the heat pipe.
- As the temperature of heat pipe raises the merit of Water and Ethanol show increase and for Ammonia it decreases. As the
- Figure of Merit increases, the required cross-sectional area of the wick decreases.Expected variations have been observed between working temperature and wick cross-sectional area ie. with increase in temperature the area increases. For Ammonia it has a sharp rise as the temperature decreases and for Water and Ethanol the area is almost constant.
- As the capacity of refrigeration is increased maximum wick area is required by Ethanol and the least is for water. The same variations can be observed between the Heat transfer Factor and Wick Cross-sectional area.
- Angle of inclination also has an interesting effect on the on the area of the wick, so the inclination has to be chosen to optimize the heat transfer, the wick area and the cost of the heat pipe.
- For the range of temperature we are dealing with maximum heat transfer factor has been obtained for Ammonia, and the area will be the maximum for the Ethanol. With increase in the pore radius the area first increases then decreases after a certain limit, hence it has to be chosen optimally. The heat transfer factor also shows a similar variation with the pore radius.
- With increasing capacity the wick area increases slightly when compared to the increase in a conventional condenser. The low wick area will render a small overall area of heat pipe.

In Future work mixture of different working fluids can be experiented with, along with different nano-particles. Also there is a scope of optimization for different types of heat pipe working on the refrigerating conditions. Different materials for the construction of the heat pipe will also be studied for their suitability for being used in refrigeration plants

References

[1] N. Kammuang-lue, P. Sakulchangsatjatai, P. Terdtoon, P. Yeunyongkul, Experimental Investigation of the Closed Loop Oscillating Heat Pipe Condenser for Vapor Compression Refrigeration, Journal of Applied Science and Engineering, 15(2), 2012, 117-18
[2] F. Korn, Heat Pipes and its Applications, Project Report 2008 MVK160 Heat and Mass Transport, Lund, Sweden, 2008
[3] J. Bonjour, F. Lefèvre, S. Khandekar, P. K. Panigrahi, Local Hydrodynamics of Flow In A Pulsating Heat Pipe: A Review, Frontiers in Heat Pipes (FHP), 1, 2010
[4] J. Hužvár, P. Nemec, Mathematical Calculation of Total Heat Power of the Sodium Heat Pipe, APVV - 0517 – 07.
[5] R. Z. Wang, Efficient adsorption refrigerators integrated with heat pipes, Applied Thermal Engineering, 28, 2008, 317–326
[6] P. Sakulchangsatjatai, P. Terdtoon, P. Yeunyongkul, Mathematical Model of the Optimum Heat Pipe Heat Exchanger for a Condenser of Vapor-Compression Refrigeration Cycle, Energy Research Journal, 1(2), 2010, 104-110
[7] R. Rajashree, K.S. Rao, **A** Numerical Study of the Performance of Heat Pipe, Indian Journal of Pure and Applied Mathematics, 21(1): 1990, 95-108
[8] A. Dwivedi, Thermodynamic Analysis of Vapour Compression Refrigeration System Using a Heat Pipe, Masters Degree in Delhi Technological University, 2015, 20-48