Analysis of Pulsating Heat Pipe in Automobile Radiator with Entropy Generation Minimization – A Detailed Review

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***Abstract:* - Flow visualization was conducted for the close loop pulsating heat pipe using charged coupled device. It was observed that during the start up period, the working fluids oscillates with large amplitude, however, at steady operating state, the working fluid circulates. The direction of circulation for the working fluid is consistent once circulation is attained, but direction of the circulation can be different For the experimental run. Phenomena such as nucleation boiling, coalescence of bubbles, Formation of slug and propagation of inertia wave were observed in the close loop pulsating Heat pipe. the finding shoe that the meandering Bends, uneven slug and plug distribution and non-concurrent boiling at the evaporator contributed to the driving and restoring forces For fluid circulation and oscillation.**

I. INTRODUCTION

A heat pipe is a heat transfer mechanism that combines the principles of both thermal Conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces. This type of heat pipe is essentially a non-equilibrium heat transfer device. A heat pipe is a container tube filled with the working fluid. Heat pipes are referred to as the semiconductors of heat due to their fast transfer capability with low heat loss. One end of this tube (called evaporator section) is brought in thermal contact with a hot point to be cooled. The other end (called condenser section) is connected to the cold point where the heat can be dissipated. A portion of the tube between evaporator and condenser is called adiabatic section. Number of PHP studies has been carried out since 1990s. Researchers agree that the oscillations are driven by an instability that appears due to coupling of the adiabatic vapor compression and evaporation/condensation mass exchange. However this instability has not been studied until recently. Such important parameters as oscillation threshold, heat transfer coefficient, and maximum heat load cannot be predicted from calculations. It is not even clear whether the oscillations are persistent or not and at which regimes. For these reasons the PHP applications are very limited. The PHP parameters are adjusted empirically, often without any certainty. To our knowledge, only a couple of small companies in the world produce them.

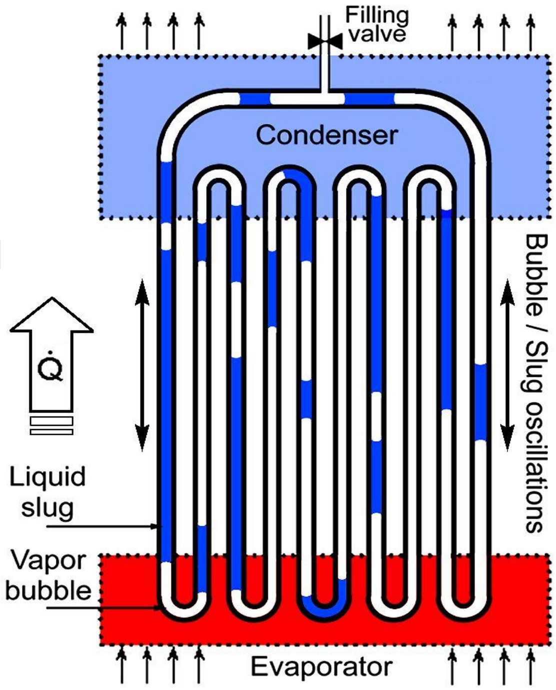

Fig 1 Pulsating Heat Pipe

II. LITERATURE REVIEW

A. Dimoudi et al [1] presented the cooling performance of a radiator based roof Component. Space cooling is getting important in most countries and different techniques have been developed one of which is radiative cooling. A prototype roof component, exploiting radiative cooling was built and tested in the outdoor test facilities of the Centre of Renewable Energy Sources in Greece. He studied that radiator efficiency is drastically reduced with increasing water flow rates. With increasing flow rates temperature difference between inlet and outlet decreases and increases with decreases cooling flow rates.

A.K.A. Shati et al [2] presented the effect of surface roughness and emissivity on radiator output. The effect of altering the emissivity and the roughness of a wall behind a radiator on the radiator heat output has been studied experimentally and by using computational fluid dynamics. The results indicate that the presence of large scale surface roughness and a high emissivity surface increases both the heat flow rate and the air velocity behind the radiator compared to a smooth shiny surface. The surface roughness will increase both the surface area for heat transfer and the turbulent intensity which increase the mass transfer and free convective heat flux through the air gap. He studied that increasing the air gap will augment heat output and heat transfer rates.

Adnan M. Hussein [3] presented Heat transfer enhancement using nano fluids in an automotive cooling system. Heat transfer enhancement using TiO_2 and SiO_2 nano powders suspended in pure water is presented. The test setup includes a car radiator, and the effects on heat transfer enhancement under the operating conditions are analyzed under laminar flow conditions. He studied that SiO_2 nano fluid produces a higher heat transfer enhancement than the TiO_2 nano fluid; likewise, TiO_2 nano fluid enhanced heat transfer more than pure water.

Ahmet Z. Sahin et al [4] presented Entropy generation in laminar fluid flow through circular pipes. Entropy generation rate in a developing laminar viscous fluid flow in a circular pipe is analyzed. The entropy generation rate is higher near the wall and sharply decreases along the radius away from the surface of the pipe. This is due to existing temperature and velocity gradient in this region. Around the centerline these gradients are small and therefore the entropy generation is small.

Benjamin Siedel, Valérie Sartre et al [5] presented Numerical investigation of the thermo hydraulic behavior of a complete loop heat pipe. He concluded that Heat losses to the ambient and through the transport lines are considered. A low evaporation coefficient leads to a large increase of the LHP temperature.

C. Oliet, A. Oliva et al [6] presented parametric studies on automotive radiator. This work provides an overall behavior report of automobile radiators working at usual range of operating conditions, while significant knowledge-based design conclusions have also been reported. He studied that overall heat transfer coefficient reveals almost independent of the air inlet temperature; but depend on coolant flow regime. Cooling capacity increases with increasing coolant and air flow. Air inlet temperature increases both heat transfer & cooling capacity decreases. Small fin spacing and higher louvered fin angles have higher heat transfer.

Ching-Ming Chiang et al [7] presented Theoretical study of oscillatory phenomena in a horizontal closed-loop pulsating heat pipe with asymmetrical arrayed mini channel. He concluded that The dominant parameters affecting the PHP dimensions of the flow channel, the number of turns, the filled liquid ratio, the frequency ratio, the operating temperature and the temperature difference between the average evaporating region and the average condensing region are investigated in this study.the closed-loop pulsating heat pipe with asymmetrical arrayed mini channel with lower number of turns, lower filled liquid ratio, higher operating temperature and higher temperature difference between the average evaporating region and the average condensing region for the frequency ratio of unity could achieve a better performance due to larger oscillatory motions.

Cihat Arslanturk et al [8] presented Optimization of a central-heating radiator. An approximate analytical model has been used to evaluate the optimum dimensions of a central heating radiator. The radiator problem is divided into three one dimensional fin problems and then the temperature distributions within the fins and heat-transfer rate from the radiator are obtained analytically. He studied that optimum radiator geometry maximizing the heat transfer rate has been obtained by using the approximate analytical model. Increase of radiator volume fraction increases the maximum heat transfer rate and optimum tube diameter.

D. Yin,H. Rajab, et al [9] presented Theoretical analysis of maximum filling ratio in an oscillating heat pipe. a maximum filling ratio to start up the oscillating motion can be found.maximum filling ratio is dependent on the working fluids and the operation temperature. Pressure difference in the system is produced, which acts as an exciting force to start up the movement of the liquid plugs and vapor bubbles in the OHP.

Dehao Xuet al [10] presented Thermo-hydrodynamics analysis of vapor–liquid two-phase flow in the flat-plate pulsating heat pipe. He concluded that with the increasing heat load, the overall temperature level of the FP-PHP increases, and the integral equivalent thermal resistance decreases.

Dong Liu et al [11] presented Flow and heat transfer performance of a mini channel channel heat sinks have relatively low Nusselt number due to small Reynolds number. the friction factor of mini-channel flow was larger than that of the macro channel flow due to larger surface roughness, and the pressure drop caused by cylinder disturbed flow was less than 5%.he studied that Distributed flow has relatively small effect on thermal resistance when velocity is slow. However the effects get stronger when velocity grows larger.

Elsayed A.M. Elshafei et al [12] presented Experimental study of heat transfer in pulsating turbulent flow in a pipe. He concluded that Observations of the local Nusselt number revealed that the heat transfer coefficient may be increased or decreased, depending on the value of frequency and Reynolds number. Higher values of the local heat transfer coefficient occurred in the entrance of the tested tube.

H. Khalkhali et al [13] presented Entropy generation in a heat pipe system. He concluded that Entropy generation in a heat pipe can also be reduced by removing the insulation in the transport section. Both the condenser ambient temperature and the convection heat transfer coincident in the transport section must be adjusted to obtain a minimum entropy generation. To reduce the entropy generation in fluid flow evaporator length should be as small as possible.

Himel Barua, et al [14] presented Effect of filling ratio on heat transfer characteristics and performance of a closed loop pulsating heat pipe. He concluded that for water, both at lower and higher heat input, lower filling ratio shows less thermal resistance and optimum heat transfer is obtained.

Huseyin Yapici, Gamze Basturk, Nesrin Kayatas et al [15] presented Numerical study on transient local entropy generation in pulsating turbulent flow through an externally heated pipe. The author analyzed the entropy generation in pulsating turbulent flow through a pipe for three different cases i.e. sinusoidal, step and saw down. The effect of the period of the pulsating flow on the entropy generation investigated. The highest temperature occurs in the step flow case. The also investigated that irreversibility due to the heat transfer dominates when Bejan number is 1.With the increase of flow period, the highest levels of the total entropy generation rates increase logarithmically in the case of sinusoidal and saw-down flow cases, whereas they do not almost change in the step-flow case.

K.Y. Leong et al [16] presented Performance investigation of an automotive car radiator operated with nano fluid-based coolants. Water and ethylene heat transfer fluids offer low thermal conductivity. With the advancement of nano technology, the new generation of heat transfer fluids called, “nano fluids” have been developed and Researchers found that these fluids offer higher thermal conductivity compared to that of conventional coolants. He studied that Heat transfer rate is increased with increase in volume concentration of nano particles. Volumetric flow rate of nano fluids is decreased with increase of volume fraction of copper nano particles.

Manfred Grol et al [17] presented closed loop pulsating heat pipes: visualization and semi-empirical modeling. He concluded that the study strongly indicates that design of these devices should aim leading to higher local heat transfer coefficients.

Maziar Mohammad et al [18] presented Overall thermal performance of Ferro fluidic open loop pulsating heat pipes: An experimental approach. He concluded that Ferro fluid improves the steady state thermal performance of OLPHPs relative to distilled water charged ones under certain conditions. Higher concentrations of Ferro fluid, reduces the steady state thermal performance of OLPHPs as a result of higher viscosity.

Mukherjee, et al [19] presented Second-law analysis of heat transfer in swirling Flow through a cylindrical duct. They calculated the rate of entropy generation. They defined also a merit function and discussed influence of swirling on this merit function.

N.Sahiti et al [20] presented Entropy generation minimization of a double-pipe pin fin heat exchanger. He concluded that shorter flow length is accompanied with lower entropy production rates. It could be shown that larger pin length sare accompanied with larger entropy production rates.

Nandan Saha et al [21] presented Influence of process variables on the hydrodynamics and performance of a single loop pulsating heat pipe. He concluded that Different kinds of flow pattern have been observed and transition of flow Pattern from oscillatory-slug to circulatory-annular .This transition is more likely in case of low FR due to a larger degree of freedom. There exists a minimum start-up power or threshold power below which no movement of fluid is observed inside CLPHP.Best performance of the loop was found to occur at an inclination angle lower than 90.

O.M. Haddad et al [22] presented Entropy generation due to laminar forced convection in the entrance region of a concentric annulus. He concluded that the total entropy generation decreases with the increase in Reynolds number. The total Entropy generation decreases as the dimensionless entrance temperature increases. Increasing the annulus radius ratio increases the entropy generation.

Piyanun Charoensawan et al [23] presented closed loop pulsating heat pipes: parametric experimental investigations. He concluded that the internal diameter of the tubes tested in the present study, as governed by the critical Bond number is well within the specified limit, bubble shapes are affected by the buoyancy forces. A certain critical number of turns is required to make horizontal operation possible and also to bridge the performance gap between vertical and horizontal operation.

Roger R. Riehl, Nadjara do Santoset al [24] presented Water-copper nano fluid application in an open loop pulsating heat pipe. He concluded that with copper nano fluid, the pulsation was better visualized. Greater amplitudes on the pulsations could be observed with the nanofluid. The presence of solid nano particles in the working to increase the nucleation sites necessary for bubble formation.

S.M.Peyghambarh et al [25] presented Experimental study of heat transfer enhancement using water/ethylene glycol based nano fluids as a new coolant for car radiators. Heat transfer performance of pure water and pure EG has been compared with their binary mixtures. Different amounts of Al_2O_3 nano particle have been added into these base fluids and its effects on the heat transfer performance of the car radiator have been determined experimentally. The heat transfer enhancement of about 40% compared to the base fluids has been recorded. He studied that with increasing the nano particles increase heat transfer rates and heat transfer coefficient. Addition of nano particles to the coolant has the potential to improve automotive and heavy duty engine cooling rates or equally causes to remove the engine heat with a reduced size cooling system.

Seyfolah Saedodin et al [26] presented Analysis of Entropy Generation Minimization in Circular Porous Fins. In porous fins, with increase of porosity, the entropy generation number will increase. Increased porosity the entropy generation will decrease. Increased that porosity the entropy generation will decrease. Also with the increase of Reynolds number, the values of entropy generation at all them will increase.

Todd A. Jankowski et al [27] presented Minimizing entropy generation in internal flows by adjusting the shape of the cross section. In adiabatic flow, the circular cross section will minimize flow resistance, which is reflected by a minimization of the entropy generation. A Duct with a large wetted perimeter will increase the surface area available for heat transfer and will minimize the overall entropy generation. When the available cross-sectional area of the flow channel is doubled, the resistance to flow in the duct is reduced, thereby reducing the entropy generation associated with fluid friction. Using larger perimeter compare to cross section area entropy generation is minimized.

Tsuyoshi et al [28] presented Numerical and experimental studies on circulation of working fluid in liquid droplet radiator. Model of the circulation of the working fluid in a liquid droplet radiator has been developed. The behavior of the circulation of the working fluid calculated from the model is compared with that obtained from experiments in the case that the flow rate of the circulating working fluid is changed. He studied that as flow rates decreases with time pressure difference in working fluid increased and this phenomena can be improved by adjusting number of revolution in gear pump used in model.

Xuefeng Wang, et al [29] presented Numerical analysis of heat transfer in pulsating turbulent flow in a pipe. The model analysis shows that Womersley number is an important parameter in the study of pulsating flow and heat transfer. Higher the womersely number benefits to heat trasfer enhancement only in entrance region.It indicates that larger velocity induced by pulsation of the fluid flow results in higher heat transfer rate.

Yuwen Zhang, et al [30] presented Oscillatory Flow in Pulsating Heat Pipes with Arbitrary Numbers of Turns. He concluded that increase in the number of turns has no effect on the amplitude and circular frequency of oscillation when the number of turn's water, functional thermal fluids (FS-39E microcapsule fluid and Al_2O_3 nano-fluid) as working fluid in PHP can enhance its heat-transport capability. Like FS-39E microcapsule fluid, Al2O3 nano-fluid as working fluid can enhance heat-transport capability of PHP.the best concentration of Al2O3 nano-fluid is 0.1 wt%.

CONCLUSION

With the increasing heat load, the overall temperature level of the FP-PHP increases and the integral equivalent thermal resistance decreases. Different kinds of flow pattern have been observed and transition of flow pattern from oscillatory-slug to circulatory-annular .This transition is more likely in case of low FR due to a larger degree of freedom. There exists a minimum start-up power or threshold power below which no movement of fluid is observed inside CLPHP.Entropy generation in a heat pipe can also be reduced by removing the insulation in the transport section. The total entropy generation decreases with the increase in Reynolds number. The total entropy generation decreases as the dimensionless entrance temperature increases. Entropy generation rate decreases due to the increase in velocity slip and temperature jump at the wall that lead to reduced heat transfer and momentum transfer from the wall to the fluid.

ACKNOWELEDGEMENT

A journey is easier when you travel together. Interdependence is certainly more valuable than independence. I would like to express our gratitude to all those who gave me the possibility to complete the seminar work. I deeply indebted to my guide DR.VIKAS PATEL & MR.HARDIK PATEL whose help, stimulation, suggestion and encouragement helped me in all the time and writing of this report.

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