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Research Paper

Synergistic analysis of heat transfer characteristics of an internally finned two phase closed thermosyphon

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HIGHLIGHTS

- A novel thermosyphon configuration with rectangular internal fins at the condenser.
- A synergistic approach by combining VOF model and lumped parameter model.
- A modified steady state theoretical model to simulate the operation of a thermosyphon.
- Analysis of effect of increasing fins inside the condenser section of the thermosyphon.

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ABSTRACT

The present study focuses on developing a hybrid heat sink with a thermosyphon having internal fins. The primary motivation behind this work is to investigate the possibility of heat transfer enhancement by addition of extended surfaces inside the condenser section of the thermosyphon. The incorporation of internal fins is expected to reduce the filling ratio and the effective thermal resistance by way of enhanced condensation. A copper thermosyphon with water as working fluid is chosen for the present study. A steady state numerical model is developed to simulate the two phase interactions. A lumped parameter code is developed and is used in conjunction with the full numerical model. In the present study the effect of varying the number of internal fins for fixed boundary conditions on the performance of the thermosyphon is studied. The computational models are validated against experimental results available in the literature. The simulations are carried out using Ansys Fluent 14 and the lumped parameter and the steady state numerical models are developed using Matlab 2012b.

1. Introduction

Due to their high conductivity, heat pipes are widely used in electronic and energy systems as heat spreaders or heat dissipation devices. Thermosyphons provide an alternative to conventional heat exchangers. A thermosyphon is essentially a gravity assisted wickless heat pipe. Since a certain amount of working fluid is trapped inside the thermosyphon at saturation pressure corresponding to the ambient temperature, any heat input will induce phase change. The vapor generated travels up due to buoyancy to the condenser section. At the condenser section, the vapor undergoes condensation and the liquid is returned to the pool. The thermosyphon is a complex two phase system which involves basically solid conduction, vapor flow and convection, pool boiling and film condensation. The falling film and the vapor flow happen in opposite directions, leading to shear at the interface which makes the modeling challenging. Fig. 1 shows the fluid cycle inside a typical two phase closed thermosyphon.

Fadhl et al. [2] and Alizadehdakhel et al. [3] carried out similar studies in modeling of thermosyphon using the Volume of Fluid (VOF) method for simulating the response of a thermosyphon for various heat inputs. Both these studies assumed a constant saturation temperature and vapor phase density, however the saturation temperature is a function of the internal vapor pressure and the vapor behaves more like an ideal gas and hence these assumptions are likely to lead to errors. Shabgard et al. [4] developed a two dimensional numerical model to study the transient operation of a thermosyphon with various working fluid filling ratios. Jouhara and Robinson [5] and Baojin et al. [6] conducted experimental investigations on thermosyphons charged with water. Dobran [7] used lumped parameter modeling for analytically determining the steady-state characteristics and stability thresholds of a closed two-phase thermosyphon. Ferrandi et al. [8] developed a lumped parameter numerical model to simulate the transient as well as the steady-state operation of a sintered heat pipe. A similar approach is adopted in the present paper. Jiao et al. [9] developed a comprehensive steady state model to investigate the effect of filling ratio

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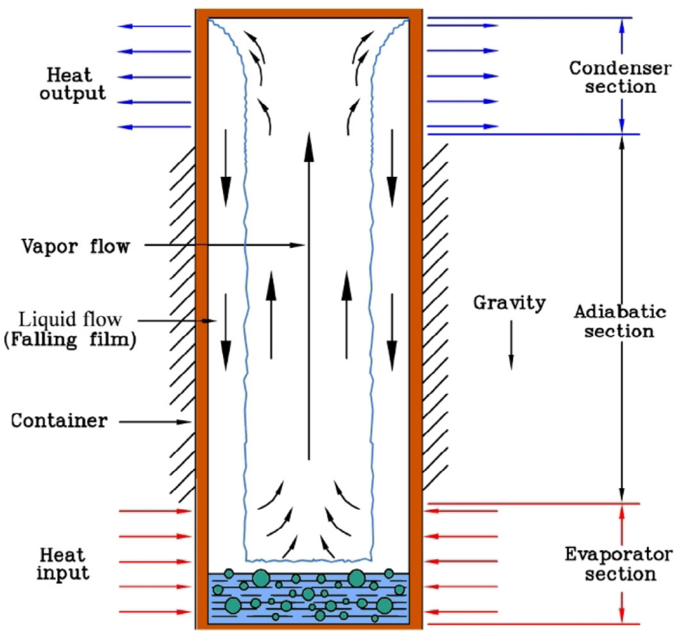

Fig. 1. Two-phase closed thermosyphon [1].

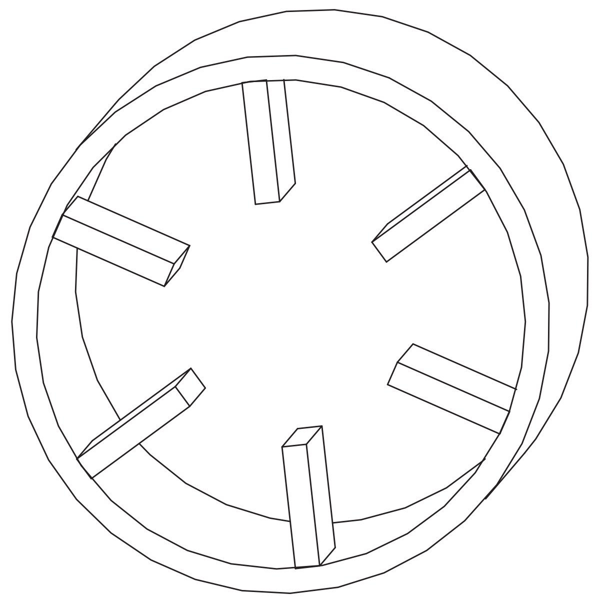

Fig. 2. A schematic enlarged view of the finned thermosyphon used in this study.

on the performance of a liquid Nitrogen charged thermosyphon. This model is adopted in this work with additional formulations for incorporating the effect of fins at the condenser.

The filling ratio of the heat pipe, defined as the ratio of the initial liquid pool volume to the evaporator volume, has a significant role in the thermosyphon operation. Many previous studies have reported that the condensation process takes place only some time after the starting of the heat pipe operation. This delayed response at the condenser can sometimes cause dry-out at the evaporator during input fluctuation due to lack of inventory of the return fluid. Hence thermosyphons are usually operated in overfilled conditions. The present work investigates the possibility of enhancement of condensation by increasing the effective area available for condensation. Extended surfaces at the condenser section however make the VOF modeling cumbersome due to the need for three-dimensional modeling which demands enormous amount of computational time. This calls for the need to develop a more simple and quick computational tool to simulate the operating characteristics of the thermosyphon with a reasonable level of accuracy. This is achieved by lumped parameter modeling. However lumped parameter estimation suffers from the shortcoming that it is a black box approach and hence a steady state model is developed for further understanding of the two-phase flow effects in the operation of the heat pipe.

2. Model

2.1. Physical model

A closed copper tube with a length of 500 mm, outer diameter 22 mm and thickness 0.9 mm is used as the thermosyphon. The heat pipe consists of a 200 mm long evaporator section, 100 mm adiabatic section and 200 mm condenser section. Water is employed as the working fluid. The model is the same as that of Fadhl et al. [2] and hence experimental results used for validating the lumped parameter model and the VOF model are those of [2]. Internal fins are incorporated at the condenser section. Following the validation, we incorporate rectangular fins inside the condenser section and study the effect on the thermosyphon characteristics. For the present study, fins of width 5 mm and thickness 1 mm are chosen. The model is tested for a fill ratio of 0.50. A schematic view of the internally finned thermosyphon used in the present study is shown in Fig. 2. Table 1 lists the input parameters for the numerical modeling.

2.2. Volume of fluid (VOF) model

The VOF model relies on the fact that each cell in the domain is occupied by one phase or a combination of the two phases. In the VOF model, the sum of the volume fractions of all phases in each control volume is equal to one. In the current work the VOF method is employed with the assumption of laminar and Newtonian fluid flow. Vapor is treated to behave as ideal gas. During phase change process, there is significant spatial and temporal variation of the properties and parameters which demand a stable numerical scheme and hence implicit scheme being unconditionally stable is used for temporal discretization of the VOF model. The modeling is based on the following assumptions:

- All the heat transfer and fluid flow processes are symmetric with respect to the axis.
- Flow field is laminar.
- The equation of state of ideal gases is used to calculate the vapor density.

The density and surface tension of water are expressed as functions of temperature following Fadhl et al. [2].

Table 1
Input parameters for numerical modeling.

Parameter	Value	Unit
Evaporator length	200	mm
Adiabatic length	100	mm
Condenser length	200	mm
Inner radius	10.1	mm
Outer radius	11	mm
Thermal conductivity of copper	385	W/mK
Specific heat of copper	8900	J/kgK
Thermal conductivity of water	0.673	W/mK
Viscosity of water	1.35×10^{-5}	Pa s

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