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ANALYTICAL MODEL AND COMPARATIVE FLUID ANALYSIS TOOL FOR SCREEN AND SINTER WICK HEAT PIPES

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1. ABSTRACT

Until now there have been no freely available tools to aid in the design and manufacture of heat pipes beyond very basic web calculators. Here, a fully parametric analysis tool to predict the performance of both sintered and mesh heat pipes in the conventional form (straight with round cross section) is presented. Its target use is aimed at aiding both the commercial design as well as more fundamental research and development of heat pipes. The authors intend to create a versatile modelling tool for rapid parametric analysis of key heat pipe variables with the additional ability to estimate the optimal wall thickness, wick thickness and fill volume for a given heat pipe outer diameter to accelerate current research and development activities. This tool is the first of its kind to contain an inbuilt database of over 350 fluids which can be readily modelled and parametrically compared with no need to integrate external fluid property databases such as 'COOLPROP' and 'REFPROP'.

2. INTRODUCTION

The design and optimisation of heat pipes for given operating conditions and geometry requirements is central to heat pipe scoping and manufacture. The analytical modelling presented in previous studies follows well established equations which have been experimentally verified under the specified flow conditions [1], [2]. Here, a demonstration of parametric analysis using the heat pipe modelling tool [3] is presented. The tool has been used in the previous works by Werner et al. to model the performance of a water heat pipe with a mesh wick [4] and to perform a comparative analysis of potential medium temperature heat pipe fluids [5].

3. METHDOLOGY

To accurately predict the capillary pressure induced upon the condensate within the wick structure, the following wick properties are estimated in accordance with the type of wick used; Equivalent Thermal Conductivity, Minimum Capillary Radius, Permeability, Porosity and Wick thickness [1].

The maximum heat load that a heat pipe can carry is determined through their operating limitations. Widely accepted analytical equations for the Capillary Limit, Sonic Limit, Entrainment Limit and Boiling Limit are used [2]. These equations carry several assumptions; incompressible flow, fully developed velocity profiles, complete pressure recovery, a low Radial Reynold's number ($Re\_r \ll 1$), uniform injection/suction into wick, and both vapour and liquid phases are in laminar flow regimes.

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In order to estimate the expected temperature drop across the heat pipe, a network thermal resistance model employed as first presented by Chisholm et al [1]. The network model is simplified to its four dominant thermal resistances; Evaporator Wall, Evaporator Wick, Condenser Wall and Condenser Wick. Liquid/vapour interface resistances and vapour phase thermal resistance are not considered in this model as these tend to be negligeable compared to wall and wick resistances. Contact resistance is also not included as this tends to be application specific and independent of heat pipe performance.

4. WORKING EXAMPLE

To demonstrate the heat pipe analytical model, Fig. 1 shows the output graphs for a heat pipe of the dimensions; 25.4mm Diameter, 500mm Length, 100mm Evaporator/Condenser Length, 100°C Operating Temperature, 3.3mm Wall Thickness, 150W Operating Power and at a horizontal orientation (0° angle) - similar to the dimensions modelled by Chi [1] (Example 2-2) for comparison. The main calculated performance predictions are; the maximum heat transport limitations (Fig. 1A and B), the heat pipe temperature difference at maximum heat load (Fig. 1C) and the effective thermal conductivity at maximum heat load (Fig. 1D).

Fig. 2 demonstrates the use of the analytical model when conducting a parametric analysis of various mesh and sinter wick porosities as well and a comparative analysis of other commonly used working fluids. Fig. 2A shows a comparison between different mesh counts, demonstrating that a 100 mesh count (i.e. a coarser mesh)

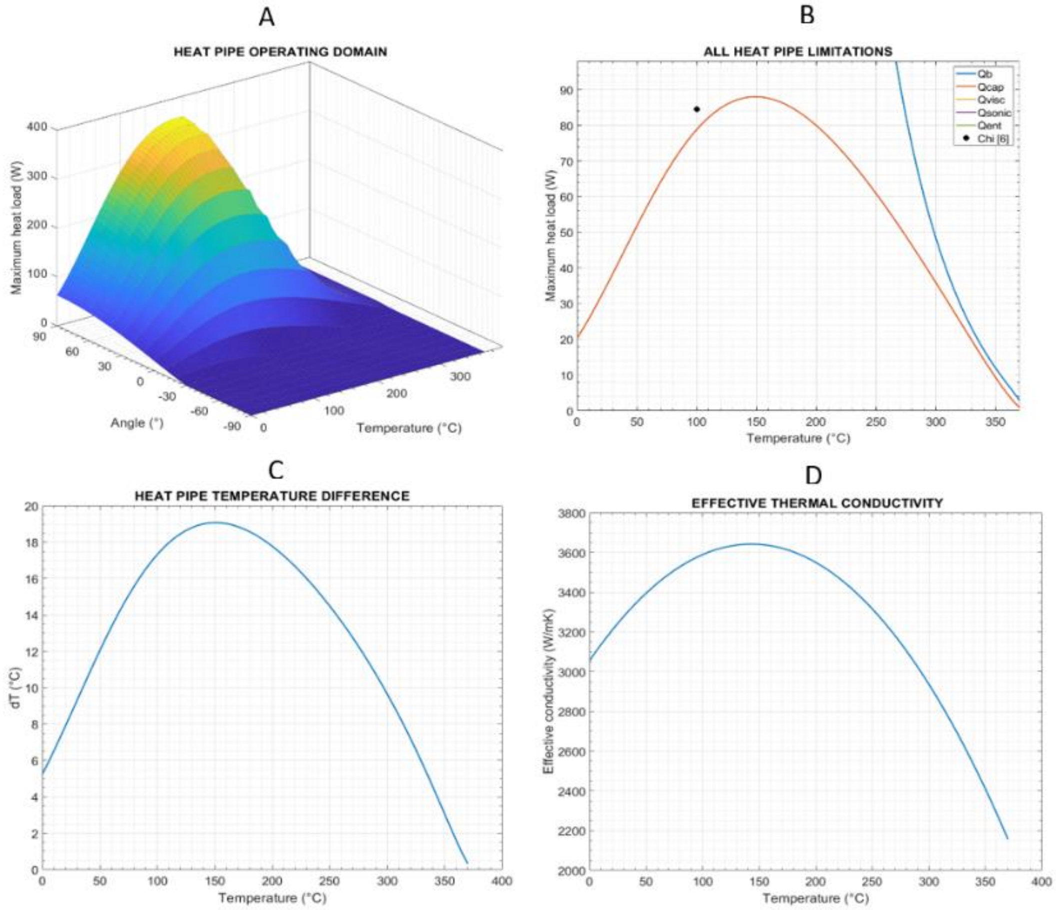

Fig. 1 Outputs form the heat pipe analytical model showing A) The heat pipe operating domain B) All heat pipe limitations C) The heat pipe temperature difference and D) The heat pipe effective thermal conductivity.

can drastically increase the maximum heat load of the heat pipe in the horizontal orientation due to the increased permeability. Equally a coarser sintered wick with larger sinter diameter will improve the maximum heat load for sintered heat pipe as seen in Fig. 2B. A comparison of other common fluids is also made for the original 200 mesh count in Fig. 2C. It can be observed that water presents significantly higher performance than Ethane, Methanol and Acetone, however these alternative fluids are able to operate at lower temperatures.

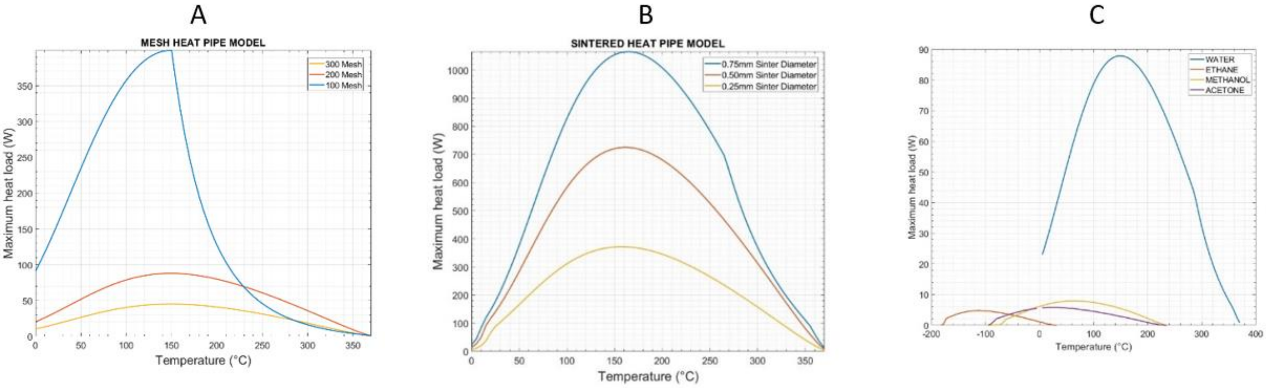

Fig. 2 Parametric wick structure and alternative working fluid analysis for mesh and sintered 25.4mmOD heat pipe model.

5. CONCLUSIONS

An analytical model with the aim of predicting heat pipe performance and facilitating the parametric analysis of mesh and sintered wick heat pipes has been developed in MATLAB [3]. This work has outlined the numerical methods used in the model and compares its performance against a working example in the text book by Chi [1]. It was found that the analytical model gives a conservative estimate for the capillary limit for mesh wicks compared to Chi. The working example successfully demonstrates the main use of the analytical model as a parametric tool for wick and fluid optimisation, as well as determination of equivalent thermal conductivity of the heat pipe for simplified thermal analysis.

The analytical model intends to be used by both academics and professional who wish to develop and optimise their own heat pipes. The analytical model will be continually developed to extend the scope and improve accuracy. Future work will be aimed at more extensive model comparisons and validation by laboratory experimentation on both mesh and sintered heat pipes.

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