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An experimental and analytical study of a variable conductance heat pipe: Application to vehicle thermal management

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ABSTRACT

This paper reports on about an analytical and experimental study of a Variable Conductance Heat Pipe (VCHP) applied to vehicle thermal management. The reduction of engine energy consumption after a cold start by controlling heating–cooling cycle of oil is the objective of the present study. A theoretical model based on a nodal method and an experimental test bench was developed to study the performance of a copper/water VCHP, using nitrogen as a non-condensable gas. VCHP operate as a thermal switch, with a start-up temperature of 80 °C. The effect of the inclination angle (i.e., adverse-gravity, horizontal position or gravity-aided) was studied. The results allowed us to identify the effect of the air mass flow rate on the condenser and the effect inclination angle on the performance of the VCHP. Our results show that the VCHP performance improves with a small inclination angle aiding liquid return to the evaporator.

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1. Introduction

Energy conversion and transportation are foundations of modern society. In the next fifty years, following the reduced availability of fossil fuels and the increasing concerns about global warming, energy will become the single most important issue facing humanity. Among all the forms of energy used today, over 70% are produced in, or through, the form of heat. In the thermodynamic cycle principle and in many industrial systems, heat must be transferred either to add energy to the system or to remove energy produced by the system. Considering the rapid increase in energy demand worldwide, enhancing the heat transfer processes and reducing the irreversibility due to the friction and heat losses have become increasingly important tasks.

Many techniques are being developed to transport heat within a device to allow it to be dissipated into the environment via conduction, natural convection, radiation, or two-phase changes, for example. Heat transport through phase change is one of the most efficient ways of transferring heat, due to the high latent heat of working fluids. The heat pipe (HP) is a comparatively recent addition to the family of systems that employ evaporation–condensation to transfer heat from a high-flux heat source to a (usually) lower flux heat sink [1–4]. It is a passive device with a fluid moving between the heat source and the heat sink. This fluid is driven by pressure pulsations caused by the internal heat transfer processes of bubble growth and collapse, in addition to natural/Marangoni convection, so they can operate in adverse or zero gravity.

Through the evaporation and condensation of a working fluid inside the heat pipe, the heat is transported from the evaporator zone, which is in contact with the heat source, to the condenser zone, which is in contact with a cold sink. A sintered-wick HP is usually made of metal, the diameter is usually less than 20 mm, and its length is between 100 mm and 500 mm. Furthermore, it provides high heat transfer rates with small temperature gradients. The equivalent thermal conductivity of a HP can be approximately 10^4 times that of copper and silver. The HP solution is very appropriate for spacecraft and land transportation requirements due to their reliability and low weight, thus making a positive impact on mission costs.

A Variable Conductance Heat Pipe (VCHP) is an active or passive control device used in applications for which there is a demand to reduce (*i.e.*, controlled conductance) or to block (*i.e.*, OFF mode) the thermal conductance during certain of the operational modes. The heat pipe conductance in a VCHP is reduced or blocked by the introduction of a certain amount of non-condensable gas (NCG) in the condensing section of the heat pipe. VCHP controls the evaporator temperature change by altering the amount of condenser

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