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Ground and microgravity results of a circumferentially microgrooved capillary evaporator

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HIGHLIGHTS

- Circumferentially grooved capillary evaporators as alternative for thermal control.
- Successful start-up operation at ground and microgravity conditions.
- Successful steady state operation at ground and microgravity conditions.
- Easy repriming in case of dry-out.

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ABSTRACT

A circumferentially microgrooved capillary evaporator is here proposed as a reliable alternative for ground and spacecraft thermal control system applications. In this paper, experimental results concerning the start-up and thermal behavior of a capillary evaporator at steady state operation are presented. A capillary pumped loop was developed and tested at ground and microgravity conditions, using deionized water as the working fluid. The capillary evaporator has internally machined circumferential grooves with an average opening of 33 μm opening at 215 μm step into a 19.05 mm (3/4 in) diameter aluminum tube. The corresponding capillary pumping pressure is about 1.5 kPa. In both tests, power inputs up to 10 W (4.55 kW/m^2) were successfully applied to the external surface of the evaporator, showing good performance under ground and microgravity conditions. The capillary evaporator as proposed proved to be a reliable alternative for industrial and space applications.

1. Introduction

Capillary pumped loops (CPL) and loop heat pipes (LHP) have shown good performance and relative reliability for ground or current spacecraft applications. Up to date, several ground tests and also flight tests have been extensively carried out using different types of capillary evaporators, most of them using tubular porous material as the capillary structure. Porous wick currently used are made of high density polyethylene, stainless steel or sintered nickel powder [1–8]. Nowadays, most LHPs and CPLs use polyethylene or metallic wicks in the evaporator. According to Santos et al. [9], there are few CPLs and LHPs which use ceramic wicks. Porous material has the advantage to produce high capillary pumping pressure, when compared with axially or circumferentially grooved surfaces. However, some operational problems remain still to be effectively solved.

Porous wick is more sensitive to NCG[1] or vapor bubbles inside the capillary evaporator due to its internal design based on circumferential tube and pores where bubble formation can block the internal flow path. Thus in order to solve this problem, circumferentially microgrooved capillary evaporators, even with their

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[1] NCG – Non Condensable Gases.

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low capillary pumping pressure, could be a reliable alternative to ground and space applications due to their different designing of liquid input where a triangular channel avoids the internal blockage caused by bubbles formation.

Experimental results have demonstrated the reliability of circumferentially microgrooved evaporators for different ground applications, for instance, solar heating using acetone as the working fluid [10]. The proposed flat plate design showed good performance for both startup and transient operation. First ground tests were carried out at IKE[2] using Freon 11 as the working fluid [11,12]. Later, tests were accomplished at UFSC[3] using acetone and ammonia as the working fluid [13,14]. The tests shown good thermal behavior and reliability even in presence of NCG [15].

This paper has the purpose to present the thermal behavior and reliability of a circumferentially microgrooved capillary evaporator for CPLs tested under ground and microgravity conditions. As far as the authors' knowledge goes, similar research concerning capillary pumping in circumferentially microgrooved evaporators have not been reported in the literature. Herein microgravity tests at ISS[4] are presented which, in its turn, showed good performance using deionized water as the working fluid. Despite of the low capillary pumping pressure, the circumferentially microgrooved evaporator could overcome the pressure drops along the vapor and liquid lines presenting to be a reliable alternative for ground and space applications.

2. State of the art

In this section it is briefly presented the state of the art regarding on the development and experimental tests of circumferentially microgrooved capillary evaporators applied to CPLs.

First researches were carried out at IKE in 90th decade. Freon 11 was used as the working fluid, showing good performance and reaching capillary pumping pressure up to 1.2 kPa [16,17]. It was shown that circumferentially microgrooved evaporators are able to overcome the pressure drops along the vapor and liquid lines even presenting low capillary pumping pressure. It is important to point out that, although this experiment presented desirable performance, experiments with Freon 11 as the working fluid are no longer used due to its ozone layer depletion potential (international agreement firmed in the Montreal Protocol).

Bazzo et al. [11] reported first results regarding seven similar capillary evaporators tested at IKE, using Freon 11 as the working fluid. The vapor and liquid lines were made of stainless steel tube with $\phi_{ext} = 40$ mm and $\phi_{ext} = 20$ mm, respectively. The capillary evaporator consisted on a group of seven circumferentially microgrooved capillary pumps made with $\phi_{ext} = 19.05$ mm (3/4 in) aluminum tube with 500 mm in length. The internal heat transfer area of each capillary pump was 0.025 m^2. In that work, the authors accomplished ground tests concerning the start-up, steady state condition, capillary limit and reprime capacity. For all the tests carried out independently of the peaks in heat load applied, the same heat transfer limit was observed (about 280 W). The cooling thermostated bath of the reservoir was set to keep the temperature at 32 °C.

Regarding on the reprime condition, the system was forced to dryout and then to reprime just by reducing the power input level in the evaporator zone. First tests evaluated the system start-up process by applying 200 W power input onto evaporator zone and then monitoring the temperature and the pressure profiles. As a result, it was observed a successful of the start-up process. This observation infers the reaching of the system steady state in such conditions. The additional power input of 30 W caused the evaporator temperature to increase from 33 to 35 °C and then the system reached new steady state condition. Afterward, the additional power input of 20 W caused the evaporator to dry-out, which was reverted by reducing back the power input for 200 W. This reduction caused the system to operate desirably in steady state condition, which was corroborated by the observation of same level of the evaporator temperature, *i.e.*, 35 °C. Thus, the full reprime capacity is just by setting of the power input at approximately 80% of the maximum power input level. Even under adverse conditions, in all studied cases no further actions such as rise the reservoir temperature, nor power input turning off were required for the system to operate properly once again after it dried-out.

Camargo [13] built a similar CPL for testing at UFSC. The CPL had a circumferentially microgrooved capillary evaporator and was tested with acetone as the working fluid. The test bed consisted of one $\phi_{ext} = 19.05$ mm (3/4 in) evaporator with 55 mm useful length. The internal heat transfer area of the evaporator was 0.0028 m^2 which is calculated based on the heated area of the microgrooved tube space. The liquid and vapor lines were made with a stainless steel tube of $\phi_{ext} = 6.35$ mm (1/4 in). The condenser consisted of one counter current concentric heat exchanger of stainless steel with $\phi_{ext} = 15$ mm and $\phi_{int} = 10$ mm and it was assisted by a first thermostated bath. A stainless steel reservoir was made with a $\phi_{ext} = 19.05$ mm (3/4 in) tube and with 500 mm length controlled by a second thermostated bath.

Camargo [13] accomplished tests for long period of about six hours under power input of 9.2 W. The reservoir temperature was set at 40 °C and the cooling thermostated bath was set at 15 °C. According to him, a temperature peak during start-up process occurred and it was caused by the presence of vapor bubbles in the liquid channel that interfered in the liquid feed behavior along the grooves. The system was only able to keep working because the bubbles were subsequently collapsed by subcooled liquid, which comes from the condenser. Tests were also carried out for 8, 16 and 28 W power inputs. The reservoir was set at 40 °C and the condenser at 15 °C. The system collapsed after 3600 s when the power was increased higher than 28 W. It was observed a reprime process when the power input was decreased to 8 W. According to this reduction, the surface temperature decreased to the same level at the beginning of the test.

Camargo [14] built another CPL similar to [13] at LabCET (Laboratory of Combustion and Thermal Systems Engineering) with $\phi_{ext} = 19.05$ mm (3/4 in) evaporator with 55 mm useful length (internal heat transfer area of 0.0028 m^2), in this experiment the working fluid was ammonia. The liquid line was made with a stainless steel tube of $\phi_{int} = 4.3$ mm and 915 mm length. The vapor line was made with a stainless steel tube of $\phi_{int} = 7$ mm and 2005 mm length. The condenser has counter current concentric heat exchanger of stainless steel with $\phi_{ext} = 15$ mm and $\phi_{int} = 10$ mm with 750 mm length. The sub-cooler was made with the same tubes of the condenser and had 350 mm length. The reservoir was also made with stainless steel tube of $\phi_{ext} = 25.4$ mm (1 in) and 450 mm length installed horizontally to minimize the influence of hydrostatic pressure in the pumping pressure. The CPL was tested with 8, 20, 34, 52, 75 W power inputs and at reservoir temperature of 35 °C. The author observed maximum temperatures lower than 38 °C and no drying-out occurrence for any of these power inputs. It was also observed a small variation in the system pressure as a function of the power input variation because the reservoir controls the system pressure. Since the evaporator temperature was controlled, the pressure of the system was also controlled independent of the power applied to the capillary pump.

[2] IKE – Institut für Kernenergetik und Energiesysteme.
[3] UFSC – Federal University of Santa Catarina.
[4] ISS – International Space Station.