Proceedings of the 9th International Conference on Fluid Flow, Heat and Mass Transfer (FFHMT'22)
Niagara Falls, Canada – June 08-10, 2022
Paper No. 128
DOI: 10.11159/ffhmt22.128

Characterization of Wick Evaporators through the Behavior of the Specially Designed Condenser

Ella Barakhovskaia[1,2,3], Andrey Glushchuk[2], Igor Marchuk[1,3], Patrick Queeckers[2], Carlo Saverio Iorio[2]
[1]Microgravity Research Center, Université libre de Bruxelles,
Avenue F.D. Roosevelt 50, CP 165/62, 1050, Brussels, Belgium
[2]Novosibirsk State University,
Pirogova Street 2, 630090, Novosibirsk, Russia
[3]Kutateladze Institute of Thermophysics SB RAS,
Prospekt Akademika Lavrent'yeva 1, 630090, Novosibirsk, Russia
Ella.Barakhovskaia@ulb.be; Andrey.Glushchuk@ulb.be, Marchuk@itp.nsc.ru,
Patrick.Quueeckers@ulb.be, Carlo.Iorio@ulb.be

***Abstract* -** New concept of the experimental investigation has been proposed and successfully realized during the 73rd ESA parabolic flight campaign 2020. The evaporators' behavior is analyzed by evaluating the liquid level inside and by investigating the external condensation on the designed condenser's surface. Three evaporators made with different techniques have been tested. Analysis of the experimental data shows qualitative differences in considered evaporators. Aluminium foam provided uniform distribution of liquid close to its external surface. The evaporator with 3D- printed wick had a non-uniform distribution of liquid inside. Sintered brass wick showed the longest stabilization time.

***Keywords*:** wick, evaporation, condensation, porous media, microgravity**,** metal foam

1. Introduction

Wick evaporators are used in various two-phase systems, and they showed good performances under microgravity conditions. The main advantage of this class of evaporators is that fluid is naturally trapped inside thanks to capillary pressure. Nevertheless, information about the behaviour of different wick types is limited. The most effective realization of capillary wicks is in Loop Heat Pipe (LHP). It is an efficient heat transfer system based on the liquid-vapour phase change phenomena. It consists of an evaporator, a condenser and some vapour and liquid transport lines. Conventionally, each design of LHP is instrumented by many non-intrusive thermocouples (up to fifty) to understand its behaviour. The standard method for assessing system stability is carried out according to the temperature and pressure measurements of the entire system. Any optical measurements are not possible since the LHPs are visually closed systems. Unfortunately, it makes it difficult to distinguish the evaporator's capability while it is affected by other elements [1].

In this work, another concept of experimental observation of the wick evaporator behaviour is proposed. Both the evaporator and the condenser are placed inside the same vapour volume with transparent walls to minimize the number of affected elements and apply various optical diagnostics. The condensed liquid is pumped back to the evaporator. The evaporators' behaviour is analyzed by evaluating the liquid level inside and investigating the external condensation on the designed condenser's surface. To apply this method, a specially designed condenser was found, the surface of which provides a stable condensate film in microgravity.

2. Experimental Setup

The condenser and the evaporator are located in one leak-tight container filled with the working fluid. HFE-7100 is used in the experiments because of its relatively low latent heat (111 kJ/kg) and low boiling point (61°C at 1 atm) relative to water. The temperature and pressure of the vapour are measured. Fig. 1 shows a top view of the experimental cell. The condenser is a single curvilinear fin surrounded with porous media. The evaporator is a cylinder with a centre made of metallic foam. The evaporator and the condenser are connected with a liquid line. Condensate is retracted from the condenser and is injected back to the evaporator by a pump. A detailed description of the used experimental setup can be found in [3].

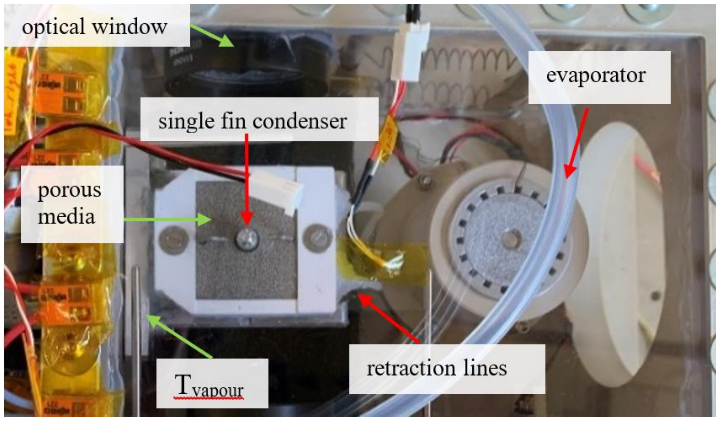

Fig. 1: Top view of the experimental cell.

The evaporator (Fig. 2a) was designed by the QinetiQ company. It consists of a distributor that dispenses liquid, a metallic porous cylinder, a metallic external tube and a low conductive jacket. The height of the porous cylinder is 55 mm, the radius is 15 mm. The tube has groves on the internal surface for the circulation of the vapour. Electrical heaters are glued on the external surface of the tube. The thermistors 10 kΩ (accuracy ±0.1 K) are inserted inside the metallic porous media close to its external surface. The position of thermistors (Tev_i, $i=1,2,3$) is the following: central sensor Tev_2, is located in the center of the porous cylinder, Tev_1 Tev_3 are located over and under Tev_2 at a distance of 13 mm. The porous media is considered without liquid if the measured temperature is higher than the saturation one at measured vapour pressure.

Three different porous materials were tested with average pore size of 200-300 μm: Aluminium foam, 3D-printed stainless steel and sintered brass (Fig. 2 b, c, d). They present various modern manufacturing methods.

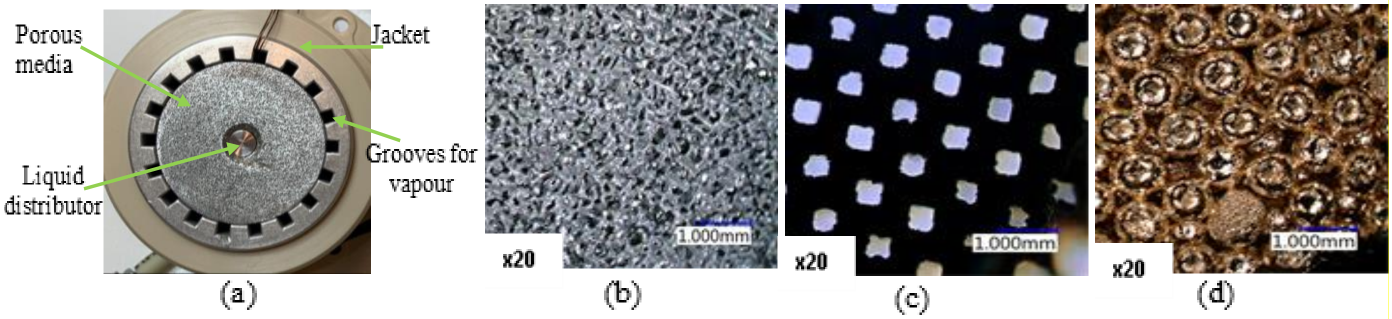

Fig. 2: (a) Scheme of the evaporator;
Porous media of evaporator: (b) Aluminum foam, (c) 3D-printed stainless steel, (d) Sintered brass

The finger-like condenser is made of Aluminium and has a height of 30 mm. The temperature of its base is maintained lower than the vapour temperature using a cooling platform. The condensed liquid is flowing along the fin surface only under the action of the capillary pressure gradient. A porous media is placed around the fin to trap the fluid and dump any liquid fluctuations during parabolic manoeuvres of the airplane. A detailed description of the porous media roles in the condensation experiment is given in [4]. An enhanced shadow optical system consists of a collimated light source and an image projection system to measure the film thickness.

3. Design of the Fin Shape

Evaporator behavior is evaluated through condenser's stability and system's pressure. Since the condensed film became an important criterion, particular attention has to be paid to condenser's shape. The film formed on the condenser's surface must be stable under weightlessness and thick enough for measuring.

A constant driving force can ensure a stable film flow. Under microgravity conditions, the dynamics of a thin condensate film on a curved surface is determined by the capillary pressure gradient proportional to the mean surface curvature gradient:

$$\partial P / \partial s = \sigma \kappa'_{fin} = -a = const\,. \tag{1}$$

A one-parameter family of axisymmetric surfaces is found, for which κ'_{fin} along the generatrix of the curve is constant. The dimensionless equation for the rotation of the generatrix of the curve $\theta(s)$ has the following form:

$$\theta'(s) + sin(\theta(s)) \Big/ \int_0^s cos(\theta(\xi))d\xi = -as + 2\,\cdot \tag{2}$$

This equation means that the κ_{fin} decreases linearly along the curve's generatrix. Thus, the capillary pressure also decreases linearly, and the capillary pressure gradient is constant. There is a single generating curve for an axisymmetric surface, for which the rotation at the inflection point takes a predetermined value. Such a curve with a radius (4 mm) at the inflection point (90°) was used to create the axisymmetric fin used in the experiments (Fig. 1).

4. Results

The investigation has been carried out during the 73rd ESA parabolic flight campaign in autumn of 2020. A detailed description of gravity variation during one parabolic manoeuvre is described by Pletser [2]. Analysis of the experimental data consists of two stages: the evaluation of the system's stability through the condenser's analysis and discovering the behaviour of the liquid inside the evaporator.

Firstly, the system's stability has been evaluated from the analysis of the condensate film behaviour. Fig.3 shows the film distributions observed. The film is thicker during the weightless period (black dots). During the hypergravity period, it is affected by the gravitational force (blue marks), and it has linear growth along the fin surface. If the film thickness was deviating significantly (grey and yellow), the system did not reach the stabilized condition for evaluation of the evaporator behaviour.

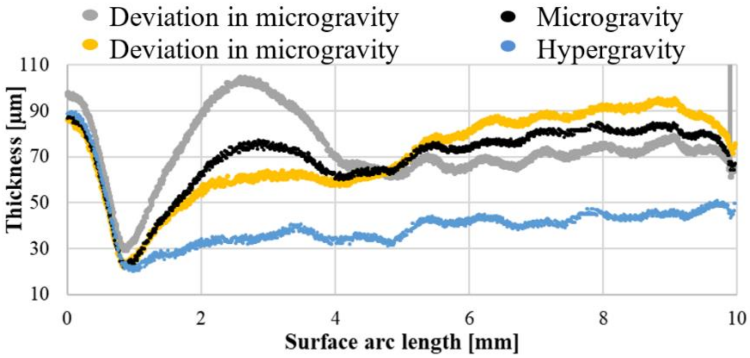

Fig.3: Condensate thickness distribution along the fin during different moments of the same parabola.

To assess the evaporator's behaviour, it is necessary to evaluate its reaction under variable gravity conditions and effective redistribution of the liquid level inside. The liquid level can be estimated by the difference between the saturation temperature corresponded to measured pressure (T_{sat}) and the temperatures inside evaporator Tev_i, $i=1,2,3$.

If $\left|Tev_i - T_{sat}\right| < 0.5°\,C$, it means that each sensor Tev_i is covered with working liquid, the evaporator is filled with the liquid. Intense evaporation is guaranteed when Tev_i is close to T_{sat} within $0.5°C$. In other words, there is a two-phase liquid-vapour interface at this level. Finally, $Tev_i >> T_{sat}$ means dry evaporator. In this case, the temperature rises continuously, and the porous area of the evaporator heats up.

We can qualitatively compare the evaporators with different porous media using these criteria, as shown in fig.3. Let us consider the most essential and demonstrative mode when the liquid is distributed along the evaporator ($Tev_i \approx T_{sat}$). Typical cases are shown on Fig.4, where red line shows gravity levels (Gr can be 1g – earth gravity, 2g – hypergravity, 0g - microgravity). Orange line is the temperature of the heater implemented around evaporator, and others lines shows temperature distribution inside the evaporator.

Aluminium foam (Fig.4a) shows the stratification of liquid levels in normal gravity and hypergravity periods. The liquid is rapidly redistributed with the onset of microgravity. It can be assumed that the liquid reaches the evaporator surface directly since $\left|Tev_i - T_{sat}\right| < 0.5°\,C$.

3D-printed stainless steel evaporator (Fig.4b) shows stronger stratification of liquid levels along the whole parabola. However, during the microgravity period, liquid redistributes, but still, $Tev_1 > 1$°C (blue line). That means that the liquid does not cover the upper sensor, and the evaporator is half full ($Tev_2 \approx 0$°C). During the parabola's second half, the liquid bouncing along the levels can be observed ($Tev_2 < Tev_3$), which can be explained due to the printed structure of the cylinder.

Sintered brass evaporator shows a quite high difference between Tev_i and T_{sat}. This can be explained by material's inertia and smaller pore size obtained by the sintering technique. It is necessary to note a prolonged evolution, starting from the microgravity period. The liquid level did not recover as quickly as in the previous cases.

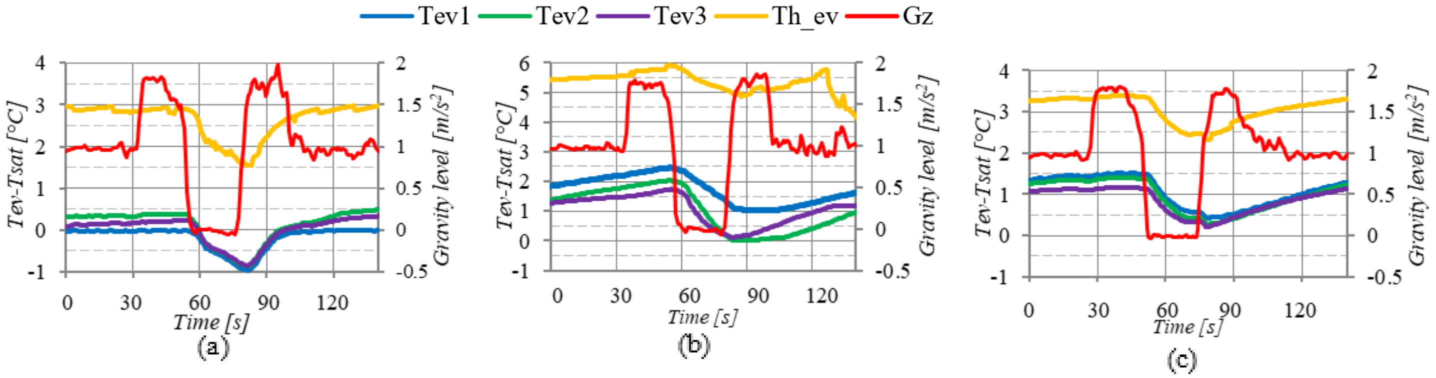

Fig. 4: (a) Aluminum foam, (b) 3D-printed stainless steel, (c) Sintered brass

5. Conclusion

The new concept of the experimental investigation has been proposed and successfully realized during the 73rd ESA parabolic flight campaign 2020. Three evaporators made with different techniques have been tested. Analysis of the experimental data shows qualitative differences in considered evaporators. Aluminium foam provided uniform distribution of liquid close to its external surface. The evaporator with 3D- printed wick had a non-uniform distribution of liquid inside. Sintered brass wick showed the longest stabilization time.

Analysis of the evaporators' behavior is ensured by the constant capillary pressure gradient on the condensate film. Numerical modelling has been performed to provide the curvilinear surface design, where such a film will be formed. In this way, the condensate is stable but sensitive to differences in vapour and fin temperatures. Thus, the condensate film's thickness on the fin's surface is a good criterion for evaporators' analysis.

Acknowledgements

This work was done under financial support of BelSPO (Belgium, Heat Transfer PRODEX) and IT SB RAS (Russia, 121031200084-2). The authors thank the European Space Agency for the 73rd Parabolic Flight Campaign and Novespace for invaluable help in the preparation of the experiment.

References

[1] S. Launay, M. Vallée, "State-of-the-art experimental studies on loop heat pipes," *FHP*, 2, 013003, 2011.
[2] V. Pletser, "Are aircraft parabolic flights really parabolic?" *Acta Astronautica*, 89, pp. 226 – 228, 2013.
[3] A. Glushchuk, C. Minetti, H. Machrafi, C.S. Iorio, "Experimental investigation of force balance at vapour condensation on a cylindrical fin," *Int. J. of Heat and Mass Transfer,* 108, pp. 2130-42, 2017.

[4] E. Barakhovskaia, A. Glushchuk, P. Queeckers, C.S. Iorio, “Stabilisation of condensate flow from curvilinear surfaces by means of porous media for space applications,” *Exp. Therm. Fluid Sci*., 121, 110283, 2021.