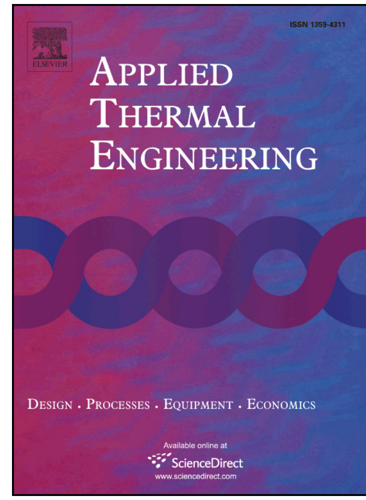
Accepted Manuscript



In situ investigation of liquid films in pulsating heat pipe

Laura Fourgeaud, Vadim S. Nikolayev, Eric Ercolani, Jérôme Duplat, Philippe Gully

PII: S1359-4311(17)30347-2
DOI: http://dx.doi.org/10.1016/j.applthermaleng.2017.01.064
Reference: ATE 9828

To appear in: *Applied Thermal Engineering*

Accepted Date: 17 January 2017

In situ investigation of liquid films in pulsating heat pipe

Laura Fourgeaud[a,b,1], Vadim S. Nikolayev[c,*], Eric Ercolani[b], Jérôme Duplat[b], Philippe Gully[b]

[a] *PSA, Route de Gisy, 78140 Vélizy-Villacoublay, France*
[b] *CEA INAC-SBT, Université Grenoble Alpes, 38000 Grenoble, France*
[c] *Service de Physique de l'Etat Condensé, CEA, CNRS, Université Paris-Saclay, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France*

Abstract

To understand functioning of the pulsating (or oscillating) heat pipe (PHP), a liquid film deposited by an oscillating meniscus is studied experimentally inside the simplest, single branch PHP, which is a straight capillary sealed from one end. The PHP capillary is of rectangular section of high aspect ratio. The evaporator is transparent so that the films can be studied by two complementary optical methods: grid deflection method and interferometry. We were able to measure both the dynamic film profile during the self induced meniscus oscillations. It has been shown that the PHP films have the same origin as those of the Taylor bubbles; their thickness right after deposition is well described by the classical formulas. Their shape however differs from the classical wedge-shaped film observed in capillary heat pipes because both of the larger thickness and of the receding triple liquid-vapor-solid contact line. The film slope is very weak, with a growing in time ridge adjacent to the contact line. It is shown that this ridge is the capillary dewetting ridge. Its dynamics is defined mainly by the capillary effects. Such results can be generalized to the conventional multi-branch PHP.

Keywords: Pulsating heat pipe, Oscillation, Liquid films, Interferometry, Optical grid deflection technique

1. Introduction

The pulsating (or oscillating) heat pipe (PHP) is a long capillary tube bent into many branches and partially filled with a two-phase, usually single component, working fluid [1]. During PHP functioning, a moving pattern of multiple vapor bubbles separated by liquid plugs forms spontaneously inside the tube. Because of their simplicity and high performance, PHPs are often considered as highly promising. Their industrial application is however limited because the functioning of PHPs is not completely understood.

During the last decade, researchers have extensively studied PHPs [2, 3]. It has been observed by many researchers that the main flow pattern inside the PHP is the slug flow, i.e. the flow of the "Taylor bubbles" where the gas is surrounded by liquid films. A major part of mass exchange occurs on their interface with the vapor like in the conventional heat pipes. Since the mass exchange provides both a moving force for the oscillations and the heat exchange, the films are extremely important for the PHP functioning.

In this presentation we concentrate on the film behavior in the evaporator because, for the PHP case, it is more complex than in the condenser where the film thickness grows more or less homogeneously. In the evaporator, the film thinning may lead to its localized drying so that its area changes and the triple liquid-vapor-solid contact line (CL) appears. The most important issues for the PHP theory are the film area and thickness. First we consider the film thickness and its evaporation dynamics and next, the CL effects that turn out to be crucial to understand the film area evolution.

2. Experimental

The studies of pure two-phase fluid case in presence of the phase change are much more scarce than in the isothermal case and for the case of different liquid and gas (e.g., water-air), see e.g. [4]. One can mention observations of condensation [5], with application to the LHP condenser. The film evaporation studies are more important for the PHP case where the partial evaporator drying occurs frequently. To our knowledge, the first film observation has been made in the U-turn (two branch) water PHP [6]. Several film observations have been carried out since then [7–9]. The film length has been measured in the single branch PHP [8]. The film profile direct measurements in the capillaries of the circular section are very difficult. For instance, it is impossible to use the confocal microscopy [9] in the cylindrical tubes, although such a method was successful for the capillary HP case. The film profile reconstruction based on the measurements of the spatial temperature distribution with the infra-red camera lacks precision either [10]. It is possible to know only the film length by this method [11].

For the present experiment, we have chosen the two-dimensional capillary, i.e. that of rectangular cross-section with the high aspect ratio, 2×22 mm^2. The experiments are carried out with simplest, single branch PHP. It is a vertical capillary of about 83 cm total length sealed from one (top) end (Fig. 1a). Its bottom end is open to a large closed two-phase reservoir regu-

*Corresponding author: vadim.nikolayev@cea.fr, Ph.: +33169089488
[1] Present address: Mechanical Design Office, Airbus Defence and Space, 31 rue des Cosmonautes, 31402 Toulouse Cedex 4, France