Materials Science-Poland, Vol. 27, No. 4/2, 2009

The influence of electric field on HFC-245fa condensation

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Condensation of HFC-245fa on a vertical cylindrical surface of a heat pipe has been studied experimentally. The temperature of the heat pipe evaporator decreased under the electric field (ac and dc). Heat transfer enhancement was observed when the electrode placed in a condenser section of the pipe was under a high voltage. The heat pipe thermal conductivity increased about 6–8% dependently of a magnitude and kind of high voltage. The best results were obtained for the straight polarity of the electrode.

Key words: *heat pipe; condensation; EHD heat transfer enhancement*

1. Introduction

The mechanism of electrohydrodynamic (EHD) enhancement, one of methods of active heat transfer enhancement, is widely used to improve heat transfer and fluid flow [1]. The electric field can enhance the heat transfer in single and two-phase systems.

In the investigations, an electric field was used to improve and control a heat pipe performance. In a heat pipe, the heat transfer depends of condensation and evaporation processes on the pipe surfaces. These processes occur in an inner surface of the pipe. A thermosyphon was used – a heat pipe with the condensing working fluid flowing to the evaporation area under the gravitational force. In previous studies of the authors, heat pipes were tested with other working fluids such as deionized water, R-141b [2] and R-365/227 [3]. The condensation section of the pipe was under the electric field operation and the evaporator was grounded. The enhancement of heat transfer during condensation has been expected for the heat pipe working with HFC-245fa.

Many examples are known of utilizing the electric field to enhance the condensation [1] but most of reports concerned external condensation on flat and cylindrical

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surfaces. According to Didkovsky and Bologa [4], Yabe et al. [5], Sunada et al. [6] and Yamashita and Yabe [7], condensation heat transfer was significantly improved by EHD for a variety of working fluids such as R-113, R-123 and other organic substances. A prototype EHD condenser was successfully built and tested by Yamashita et al. [8]. The EHD-assisted external condensation of R-134a on smooth horizontal and vertical tubs was investigated by Cheung et al. [9]. Butrymowicz et al. [10] described a novel EHD method of condensate drainage from horizontal finned tubs (experiments with R-123).

The heat transfer mechanism involves an effective removal process of liquid condensate from the heat transfer surface, minimizing the film thickness by utilizing the EHD-induced forces. However, this requires a careful design of the electrode to yield a maximum enhancement at minimum power consumption.

2. Experimental

A dielectric heat pipe (DHP) has been constructed, where the condensation section was separated from the evaporation section by a high voltage insulator. Measurements of DHP characteristics and testing of DHP performance were conducted within the system presented in Fig. 1.

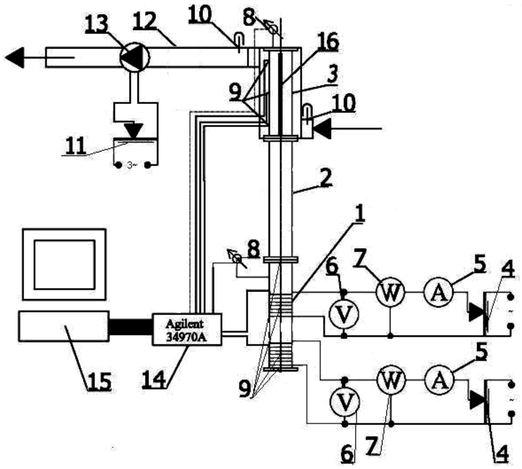

Fig. 1. Schematic of experimental arrangement for the DHP testing

Dielectric heat pipe consists of an evaporator (1) being a segment of a copper pipe with the dimension 22×1 mm and 2×30 cm long, an electric insulator (2) composed of two parts of a teflon-epoxy pipe 30 cm long, with the dimension 40×10 mm and a condenser (3) made of a bronze pipe with the dimension 26×3 mm 93 cm long. Six copper fins was put on the external surface of the condenser. The whole condenser was placed in a steel pipe with the dimension 125 mm, where flows cooling air. The tested pipe was placed in a vertical position to enable the gravitational flow of condensate from the condenser to the evaporator.

Heat was delivered to the evaporation section (1) by means of an electric heater which was placed on the outer surface of the evaporator. Electric power of the heater was controlled by an autotransformer (4). Power measurement was made by means of a wattmeter (7). Additionally, the power supply system was connected with a voltmeter (6) and an ammeter (5). Heat flux transferred from the working fluid to the DHP condenser (3) was taken out to the surroundings by forced convection. Copper fins were placed along the outer surface of the condenser for increasing the cooling area. The condenser was put into the duct (12) where the cooling air flows. The ventilating fun (13) sucks air in the room and then after heating up, it is exhausted through the wall outside the building. The fun flow was controlled by an autotransformer (11).

Two air temperature sensors Pt 100 (10) were mounted into the air duct (12). The pipe surface temperatures were measured by means of K-type thermocouples (9). The pressure sensors (8) were installed in a condenser and an evaporator. The measuring data was recorded using a data acquisition system Agilent HP 34970A type (14) and PC (15).

A high voltage source for DHP was the high voltage transformer in the case of ac or electric feeder in the case of dc+ and dc– polarity. High voltage was applied to a copper rod introduced axially into the condensation section. The rod (16) (bar electrode) had the diameter of 8 mm.

3. Results of experiment

In order to check how electric field affects the performance of DHP operating with HFC-245fa, the measurements of thermal characteristics for the pipe model have been made. After applying a high voltage to the bar electrode inside the condenser, the radial component of electric field (perpendicular to the liquid–gas interface) was forced. In this way, an electric field can effect vapour and liquid of working fluid in DHP condensation section.

The DHP working with HFC-245fa was tested for transferred heat in the range of 300–500 W. The following measurements were done: the temperature distribution on the pipe surface, heat transferred through the pipe, pressure inside the pipe, voltage applied to the electrode. Experiments were taken for a fixed value of heat transfer and various voltages: ac and dc (for both polarities) in the range of 0–20 kV. For voltages higher than 25 kV, the breakdown was observed.

Under the electric field (ac and dc), the temperature on the evaporator decreased and the difference between temperatures of the evaporator and condenser decreased as well. The strongest effect of electric field was observed for dc+. Decreasing temperature in the evaporator can be connected with enhancement of condensation heat transfer in presence of electric field. The augmentation of condensation flow let to intensive evaporation and consequently a decrease of temperature of electric heaters was observed.

Decreasing of the difference of temperatures between the evaporator and condenser for fixed heat transfer causes that the DHP thermal conductivity (1) increases. The DHP thermal conductivity is the ability of the pipe (with a given length and dimension) to transport heat for a given difference of temperatures between the evaporator and condenser sections:

$$\lambda = \frac{QL}{\Delta TF} \tag{1}$$

where: λ is the DHP thermal conductivity, W/(m·K), Q – heat transported through DHP, W, F – cross-section area of DHP, m^2, L – DHP length, m, ΔT– difference of temperatures between the evaporator and condenser sections, K.

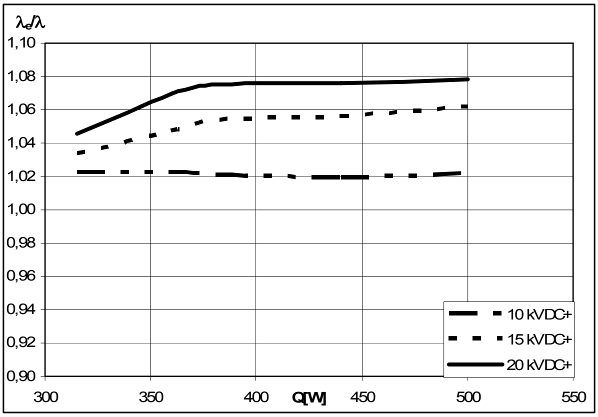

Fig. 2. The relative thermal conductivity of DHP versus the heat transfer (dc+)

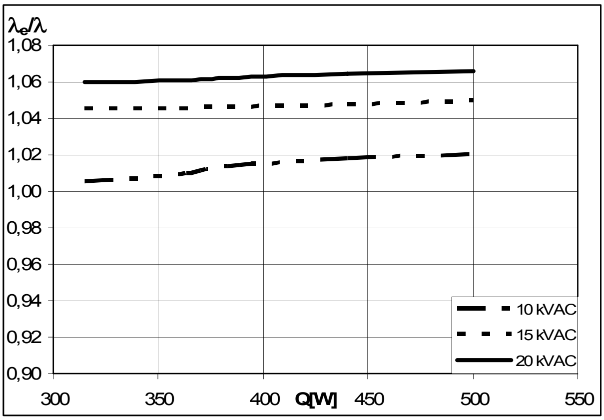

Fig. 3. The relative thermal conductivity of DHP versus the heat transfer (ac)

Figures 2 and 3 show a relative thermal conductivity of DHP; the thermal conductivity for the pipe under high voltage was compared to the thermal conductivity with-out voltage. By increasing the electric strength (i.e. the applied voltage), the thermal conductivity of DHP could be increased. Analyzing results of the experiments, we can find that the heat pipe performance could be enhanced by dc+ electric field. Maximum augmentation of the thermal conductivity was about 8% and it was observed for voltages exceeding 15 kV (which corresponds to the electric field strength 1600 kV/m on the condenser surface).

Enhancement of heat transfer was observed also for ac electric field and the maximum augmentation of the thermal conductivity was about 6%. Similarly as for dc+, the effect of electric field was observed for voltages exceeding 15 kV (for the electric field strength 1600 kV/m on the condenser surface).

4. Conclusions

The effect of electric field on condensation of HFC-245fa on a vertical, cylindrical surface has been studied experimentally. The condensation was observed on the inner surface of the heat pipe. Electric field influenced not only condensation of HFC-245fa (working fluid in the heat pipe) but the performance of the whole heat pipe. After applying high voltages (ac and dc) to the bar electrode inside the condenser, decreasing of temperature in the evaporation region was observed. It caused that the thermal conductivity of the heat pipe increased maximally about 6–8%, depending on the kind and magnitude of electric field. The highest augmentations were observed for dc+ electric field. The effect of electric field could be connected with the destabilization of liquid-vapour interface in a condensation region of the heat pipe.

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Received 13 July 2007
Revised 12 August 2007