International Journal of Heat and Mass Transfer 82 (2015) 521–529

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Heat transfer performance of an anodized two-phase closed thermosyphon with refrigerant as working fluid

A. Brusly Solomon [a,*], R. Roshan [a], Walter Vincent [a], V.K. Karthikeyan [b], L. Godson Asirvatham [a]

[a] Centre for Research in Material Science and Thermal Management, School of Mechanical Sciences, Karunya University, Coimbatore 641114, India
[b] Department of Mechanical Engineering, Sri Ramakrishna Engineering College, Coimbatore, India

ARTICLE INFO

Article history:
Received 29 July 2014
Received in revised form 7 October 2014
Accepted 7 November 2014
Available online 26 November 2014

Keywords:
Anodization
Thermosyphon
Electronic cooling
Porous coating
Refrigerant

ABSTRACT

Heat transfer characteristics of an anodized two-phase closed thermosyphon (TPCT) with refrigerant as the working fluid is studied and compared with that of a non-anodized one. A simple anodization is performed to make a porous structure on the inner wall of TPCT. The anodized and non-anodized TPCTs charged with a blend of R600a and R290 are tested for the heat input range of 50–200 W. The effects of filling ratio, inclination angle, heat input and anodized surface on the performance of the TPCTs are investigated. Due to the anodization, the evaporator heat transfer coefficient enhances up to 33% at the inclination angle of 45° for the heat input of 200 W. Also, total thermal resistance of the anodized TPCT is reduced by 17%, 20% and 23% respectively for horizontal, inclined and vertical positions when compared to the non-anodized TPCT. Enhancements in the surface area, number of nucleation sites, increased bubble frequency, intensified bubble interaction and thin film evaporation are major factors for the performance enhancement in the anodized TPCT. Also it is found that the filling ratio, inclination angle and heat input have a significant role on the performance of the TPCT.

1. Introduction

Every day, cooling requirement in electronic industries increases abruptly due to greater functionality, faster operation, reduction in size and weight, and cost reduction of electronic products. Combination of faster operation and reduction in size resulted in high volumetric heat generation in electronic components leading to failure in the electronic device. Hence high performance heat dissipation devices are required to meet this demand. TPCT is one of the promising devices and hence, it is adopted for electronic cooling applications [1]. Also the device is used in many applications such as energy storage system [2], thermoelectric power generators [3], power electronics [4], seasonal cooling load reduction of buildings [5], refrigeration systems [6], cooling super conducting bearings [7], boiler application [8], and heating and cooling applications [9]. A thermosyphon is a two-phase heat transfer device that transports heat from one point to another by phase change mechanism. In which the heat transfer takes place through evaporation and condensation processes, and the working fluid is re-circulated from the condenser to the evaporator by gravitational force. However, in some cases, the working fluid is re-circulated by capillary forces. Since the high performance weightless TPCTs are demanded in industries, many investigations have been performed by altering the design and working fluids.

Recently, nanofluids [10–17] have been incorporated into the TPCTs and found substantial enhancement in the heat transfer of the device. Liu et al. [10] conducted a performance study on a miniature TPCT with CuO/water nanofluids. In another study, Liu et al. [11] studied the performance of open type thermosyphons using CNT/water nanofluids. Lu et al. [12] carried out an experiment to study the thermal performance of an open type thermosyphon with CuO/water nanofluids. Khandekar et al. [13] analyzed a TPCT with pure water and various water based nanofluids (Al_2O_3, CuO and laponite clay) as the working fluids. Noie et al. [14] studied the efficiency enhancement of a TPCT with Al_2O_3/water nanofluids. Parametthanuwat et al. [15,16] conducted an experimental study to analyze the heat transfer characteristics of a TPCT with Ag/water nanofluids. Huminic et al. [17] conducted an experimental study to analyze the effect of iron oxide/water nanofluids on the performance of TPCT. Furthermore refrigerants and refrigerant based nanofluids were also used as potential working fluids in TPCTs for low temperature applications. In this context, very few

* Corresponding author.
E-mail address: brusly_solomon@yahoo.co.in (A.B. Solomon).

http://dx.doi.org/10.1016/j.ijheatmasstransfer.2014.11.034

Nomenclature

$c_{p,l}$	specific heat of coolant fluid (J/kg K)
d	diameter of the tube (m)
D_b	bubble diameter (m)
f	bubble frequency (1/s)
h	heat transfer coefficient (W/m^2 K)
T	temperature (°C)
k	thermal conductivity (W/m K)
l	length (m)
$\dot{m}_i$	mass flow rate of coolant (kg/s)
N_a	active nucleation site density (sites per m^2)
Q	heat transfer rate (W)
q	heat flux (W/m^2)
R	resistance (°C/W)
r	radius (m)
ρ	density (kg/m^3)

Subscripts

hp	heat pipe
out	outlet
in	inlet
e	evaporator
c	condenser
e,i	evaporator inner wall
c,i	condenser inner wall
sat	saturation
o	outer
T	total
l	liquid

investigations have been performed to study the performance of TPCT [18–21]. In the past few decades, the performances of TPCTs with R-11, R-12 and R-22 as the working fluids were studied. However, R-11 and R-12 were banned due to high ozone depleting potential and hence to reduce the risk of ozone depletion, R-134a was used in later investigations [18,19].

From the above literatures [10–17], it was observed that the performance of the TPCT was enhanced/deteriorated due to the deposition of nanoparticles. However, most of the experiments revealed that the performance of the TPCT enhances [10–12,14–17]. The reason for the performance enhancement/deterioration depends on the mechanism behind the heat transfer. The thermo-physical properties [16] of nanofluids and formation of thin porous coating [12] in the evaporator are responsible for the heat transfer enhancement. Previous experiments by the present author [22,23] and other experiments [24,25] confirmed that the thin porous coating on the wall plays a vital role in the heat transfer enhancement. Hence, the present study is performed to predict the effect of thin porous coating on the performance of TPCT. Anodization process has been known to produce a uniform porous coating over the past several years. Also it is noticed that none of the researchers studied the performance of an anodized TPCT with refrigerant as a working fluids. Hence in the present study, the effect of anodization on the performance of TPCT is studied using refrigerant as the working fluid. The effects of filling ratio, heat input and the inclination angle on the performance of TPCTs are also investigated.

2. Experimental details

2.1. Preparation of coating

Anodization is performed to prepare a uniform porous coating at the inner wall of TPCT. Before anodization, necessary cleaning process is performed to ensure a uniform and stable coating. The test section consisted of an aluminum tube with an inner diameter of 16.5 mm and length of 350 mm. The aluminum tube and a stainless steel rod (SS303) are considered as an anode and cathode respectively. The diameter of the cathode is considered as 10 mm. The cathode is placed at the inner side of the anode with a distance of 3 mm from the anode. To avoid a physical contact between anode and cathode, Teflon sleeves are used at both ends of the anodizing cell. A constant temperature is maintained at the cell assembly by circulating cooling water around the entire anodize ng cell setup. The anodization process involves two steps, which are pre-treatment and internal anodic oxidization. For the pre-treatment, 50 g/l NaOH solution is circulated through the gap between the anode and cathode for 2 min followed by DI water is circulated for about 5 min. Afterwards, impurities are removed by circulating 10 vol.% HNO_3 solution for 2 min. Following that DI water is circulated for 5 min and rinsed. After the pre-treatment process, internal anodic oxidization is performed by circulating electrolytic solution (10 vol.% H_2SO_4). The uniform coating is achieved by using the optimized anodizing conditions of 10 vol.% concentration,

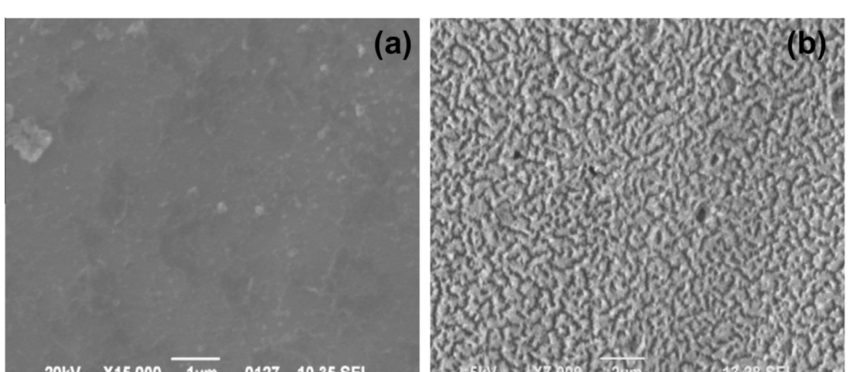

Fig. 1. SEM images of (a) non-anodized and (b) anodized surface.