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Experimental study of pressure rise at the evaporator of capillary pumped loop with acetone and water as working fluids

Paweł Szymański [a,*], Dariusz Mikielewicz [b]

[a] *Faculty of Ocean Engineering and Ship Technology, Gdansk University of Technology, Poland*
[b] *Faculty of Mechanical Engineering, Gdansk University of Technology, Poland*

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ABSTRACT

In this work studied is the possibility of fluid pumping using capillary forces in the capillary pumped loop. Experimental and theoretical studies have been performed to understand the phenomena associated with heat transfer in porous structure of the evaporator. The capillary effect was studied during operation of two different capillary porous structures with two different working fluids, namely water and acetone. The results gave a foundation for a new concept of modern evaporator for waste heat recovery that supports the fluid pumping in the thermodynamic cycle. The results shows that evaporator filled by capillary wick made of Ni-Cu sintered porous material can produce the pressure difference up to 1.63 kPa at the heat rate input of 100 W.

1. Introduction

Applications utilizing cogeneration and recovery of waste heat are a promising new direction of modern dispersed energy sector development. One such example that could, in the future, supplement the centralized energy sector is the micro-CHP combined heat and power unit (micro-CHP) operating according to the Clausius–Rankine cycle. In such installations usually other than water fluids are used, namely the low-boiling point fluids. In case of implementation of the latter fluids there arises a problem of excessive demand for pumping power. Using capillary forces for pumping working fluid in the organic Clausius–Rankine (ORC) is a new idea that allows for reduction or even elimination of the pumping device the working fluid in such cycles. Evaporator filled by porous material that pumps the working fluid in the system, could also be used for other industrial applications where ORC can be used, such as or example micro-CHP heat and power plants for single households, refrigeration and air conditioning systems etc. The use of capillary forces will reduce the pumping power required for circulating pump operating in a thermodynamic cycle (which in case of low-boiling fluids is significant), thus reducing power consumption, which gets the circulating pump, and consequently reduce CO_2 emissions and limit the environment degradation.

There are typically two types of capillary action aided devices. A two-phase pump loop with porous structure, namely the Loop Heat Pipe (LHP), is an efficient heat transfer system based on the liquid-vapor phase change phenomena. The device consists of an evaporator, condenser, compensation chamber and finally the vapor and liquid transport lines. Only the evaporator and eventually the compensation chamber contain wicks, while the other components could be made of smooth tubing. A two phase capillary loop uses capillary action to circulate the working fluid in a sealed enclosure. Another two-phase capillary pump loop, named Capillary Pumped Loop (CPL), has similar advantages as LHP compared to heat pipe. The basic distinction between a traditional CPL and a traditional LHP lies in the fluidic and thermal attachment of the compensation chamber to the evaporator.

Although conventional capillary pumped loop technology has been successfully applied in the last thirty years for the thermal management of a variety of applications like space applications, electronic cooling and high power devices cooling, to cite a few [1–10]. Using capillary forces in evaporator for pumping a working fluid in thermodynamic cycle (*eg.* ORC) is a new idea, that allows to reduce or even eliminate the device that pumping working fluid in such cycle. Application and principle of operation of such evaporator was presented by the authors in previous works [11,12].

Evaporator in the CPL serves three functions: (1) to prevent the reflow of vapor into liquid inlet, (2) to pump the working fluid from the condenser to the evaporator to form natural circulation, (3) to

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[*] Corresponding author.
E-mail addresses: pawszym1@pg.gda.pl (P. Szymański), dmikiele@pg.gda.pl (D. Mikielewicz).

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Nomenclature

A	cross-sectional area (m^2)
d	diameter (m)
h_{lv}	latent heat of vaporization (kJ/kg)
L	length (m)
$\dot{m}$	mass flow rate (g/s)
p	pressure (Pa)
$\dot{Q}$	heat load applied to evaporator (W)
r	radius (m)
Re	Reynolds number

Greek symbols

v	velocity (m/s)
ρ	density (kg/m^3)
κ	permeability of the wick (m^2)
ε	wick porosity (%)
σ	surface tension (N/m)
μ	dynamic viscosity (Pa s)

Subscripts

bayonet	bayonet
cap,max	maximum capillary pressure
cc	compensation chamber
cond	condenser
evap	*evaporator*
grooves	vapor grooves
l	liquid
ll	liquid line
in	internal radius of the wick
out	external radius of the wick
p	pore
wick	wick
v	vapor
vl	vapor line

provide the working fluid a flow path from the evaporator to condenser.

In this work studied the possibility of pumping fluid using a capillary forces in CPL evaporator. The potential application of such a heat exchanger is for example an evaporator of the domestic micro-CHP unit.

2. Experimental design

A CPL with exchangeable evaporator was manufactured and tested in order to evaluate its thermal performance and possible capillary pressure difference created by the evaporator. The pressure rise at the evaporator was measured while the thermal load was varied. In this study tested were two evaporators filled by two different wick materials in cooperation with two different working fluids, namely water and acetone. **The first evaporator** consists of a cylindrical tube filled with the sintered porous wick made of the mixture of nickel and aluminum. This sinter is fully permeable, the pore size radius is 2,5 μm, permeability is around 5.42×10^{-13} m^2, and porosity is 55%. **The second evaporator** is filled by a porous wick made by a sinter of nickel copper powders. This material is also fully permeable, the pore size radius is 2,5 μm, permeability is 5.88×10^{-13} m^2 and the porosity is 60%. Both evaporators have the same construction and both have 10 vapor grooves of 1.7 mm diameter each. In the above mentioned evaporators, vapor channels are located at the surface of the evaporator housing and have been drilled within the porous structure. The geometrical dimensions of the evaporators are shown in Fig. 1 and the appearance is presented in Fig. 2.

Fig. 2. Evaporator filled with a wick. Ni-Cu (left side) and Ni-Al (right side).

The evaporator housing is made of stainless steel with a wall thickness of 1 mm. This material was used because of the possibility of testing various liquids to eliminate any destruction (corrosion) of the casing material through testing an incompatible fluids.

For the heating of the capillary evaporator, electrical resistant wire of heating power of 100 W was wound around wick section of evaporator casing and connected to laboratory DC supplier with adjustable voltage and current. The electric power applied to the electric resistor was calculated by measuring the current and voltage across it. Assuming no heat loses through the insulation in the heating zone, the applied electrical power is taken as the rate heat

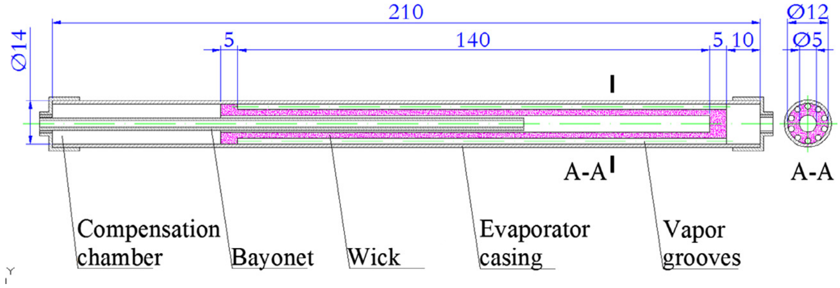

Fig. 1. The outline of evaporator with relevant dimensions (in scale).