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Effect of using nanofluids on the performance of rotating heat pipe

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ABSTRACT

Nanofluids have novel properties that make them potentially useful in many heat transfer applications. This paper presents a study on the effect of using nanofluids on the performance of rotating heat pipe. The effect of using nanofluids on the heat transfer and liquid film thickness is carried out. Three solid nanoparticles are used Cu, CuO and Al_2O_3 at different nanoparticles radiuses and volume fractions with water as working fluid. A mathematical model is presented of the rotating heat pipe including vapor velocity, gravity and taper angle effects. The study is carried out at different rotation speeds (ω), temperatures differences of the heat pipe (ΔT) and masses of working fluid of the heat pipe. For a given mass introduced to the rotating heat pipe, using of nanofluids with the heat pipe decreases the liquid film thickness adjacent to its walls and increases the heat transfer by the heat pipe compared with essential fluid. The results show that the heat transfer by rotating heat pipe increases with increase ΔT and volume fraction and radius of solid nanoparticles and with decrease condenser taper angle. The maximum heat transfer by rotating heat pipe increases with using nanofluids despite of increasing the minimum mass introduced the heat pipe. Rotating heat pipes with Cu–water nanofluid have maximum heat transfer compared with CuO–water and Al_2O_3–water nanofluids. The maximum heat transfer by rotating heat pipe at $\Delta T = 20$ °C and $\omega = 3000$ rpm increases by about 56% due to using Cu–water nanofluid with Cu nanoparticles of volume fraction 0.04 and radius 5 nm.

1. Introduction

It is widely known that there are many types of heat pipe, which depend on various mechanisms to return the condensate to the evaporator section such as; using a gravity force, a capillary structure, an osmotic membrane or employing centrifugal force. Centrifugal force seems to be an appropriate mechanism for rotary equipment and the heat pipe depending on centrifugal force mechanism is called "rotating heat pipe". The rotating heat pipe was invented by Gray [1,2] and it utilizes centrifugal acceleration to transfer liquid from the condenser to the evaporator. The rotating heat pipe does not of course suffer from the capillary pumping limitations which occur in conventional heat pipes and its transport capability can be greatly superior to that of wicked heat pipes [3]. The rotating heat pipe, like the conventional capillary heat pipe, is divided into three sections, the evaporator, the adiabatic and the condenser. However, the rotation about the axis will cause a centrifugal

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Nomenclature

C	specific heat capacity J kg^{-1} K^{-1}
g	gravity m s^{-2}
h_{fg}	latent heat of evaporation J kg^{-1}
L	heat pipe length m
L_a	adiabatic section length m
L_c	condenser section length m
L_e	evaporator section length m
m	mass of working fluid kg
$\dot{m}$	lineic mass flow rate kg m^{-1} s^{-1}
p	pressure pa
q	heat transfer per unit area W m^{-2}
Q	heat transfer W
R	heat pipe radius m
r_{np}	nanoparticles radius nm
s	thickness
T	temperature K
u, v	velocity m s^{-1}
x, y	coordinates m

Greek symbols

λ	thermal conductivity W m^{-1} K^{-1}
μ	dynamic viscosity Pa s
ρ	density kg m^{-3}
ϕ	volume fraction
δ	liquid film thickness m
α	taper angle
ω	rotation angle rad s^{-1}
τ	shear stress N m^{-2}

Subscripts

a	adiabatic
c	condenser
e	evaporator
eff	effective
l	liquid
nl	nanolayer
nf	nanofluid
np	nanoparticle
s	saturated
v	vapor
w	wall

acceleration with a component along the wall of the pipe. The corresponding force will cause the condensed working fluid to flow along the wall back to the evaporator region. Rotating heat pipes have been successfully used in cooling electric motors and generators and could be used in drill bit cooling [4]. Many rotating heat pipe investigations have been accomplished concerning the internal heat transfer and hydrodynamic performance with internal great diameters [5,6]. Studies of rotating miniature heat pipes diameters less than 10 mm, have recently started and some results regarding steady state performance and heat transfer capacity have been reported [7]. Li et al. [8] built a model equipped to predict the flow and heat transfer features of a conical rotating heat pipe of rotational speed range between 600 and 1200 rpm and for heat load from 0.1 to 1.2 kW. They assumed negligible shear stresses at the liquid/vapor interface, constant pressure in the vapor, and liquid film thickness equal to zero at both the beginning of the condenser and the end of the evaporator. Faghri et al. [9] modeled vapor flow inside a cylindrical axially rotating heat pipe by solving two dimensional axisymmetric differential equations for the conservation of mass and momentum in the cylindrical coordinates at rotational speeds (0 to 2800 rpm) and for radial Reynolds number from 0.1 to 20. They found that when the rotational speed increases, the centrifugal forces tend to compress the fluid toward the inner pipe's wall, thereby creating annular distribution. Waowaev et al. [10,11] studied the heat transfer characteristics of a radial rotating heat pipe depending on the inner diameter of the tube, aspect ratio, rotational speed, working fluid and the dimensionless parameters of heat transfer. They found a tendency for heat flux to gradually decrease with an increase in aspect ratio and to increase with an increase in rotational acceleration in horizontal conditions. The heat