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Development and investigation of a loop heat pipe with a high heat-transfer capacity

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HIGHLIGHTS

- An ammonia LHP 21 m long has been developed and tested.
- Tests were conducted at a horizontal orientation and heat sink temperatures of 4 °C and 20 °C.
- The LHP demonstrated serviceability in the range of heat loads from 200 to 1700 W.
- The minimum value of the "heat source – heat sink" thermal resistance was at a level of 0.034 °C/W.

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ABSTRACT

Loop heat pipes (LHPs) are passive heat-transfer devices which may be used in energy-efficient systems of recovery of low-potential heat, for heat transfer from renewable energy sources, and also in systems of thermal regulation of different equipment with remote heat sinks or sources. The paper shows the results of development and thermal tests of an LHP 21 m long made of stainless steel with ammonia as a working fluid. The device had a cylindrical evaporator 24 mm in diameter with an active zone length of 188 mm equipped with a nickel wick with an effective pore radius of 1.05 μm and a porosity of 70%. The LHP condenser made in the form of a pipe-in-pipe heat exchanger 310 mm long was cooled by running water with a temperature of 4 °C and 20 °C. Tests were conducted at a horizontal orientation of the device. At a cooling temperature of 20 °C a maximum heat load of 1700 W (12 W/cm^2) was achieved at a vapor temperature of 62 °C, which corresponded to a heat source temperature of 89 °C. In this case the thermal resistance of the "heat source – cooling liquid" system was equal to 0.034 °C/W.

1. Introduction

Loop heat pipes (LHPs) are two-phase heat-transfer devices operating on a closed evaporation-condensation cycle and using a capillary pressure for pumping the working fluid [1]. A capillary pressure is created in a capillary structure (wick) located in the LHP evaporator. The evaporator is connected with the condenser by means of smooth-walled pipelines, which act as a vapor and liquid lines. The schematic diagram of the LHP is given in Fig. 1. The capillary structure in the LHP acts simultaneously as "a capillary pump" and an efficient evaporative heat exchanger with a low thermal resistance. As a capillary pump, the wick is capable of creating a pressure sufficient for the transportation of a working fluid for distances estimated in meters or even tens of meters. The low thermal resistance of the evaporator is ensured by the high heat of evaporation of working fluids that are usually used in LHPs, the vast surface of the evaporative menisci in the wick, which has a pore radius from 1 to 10 μm and a porosity of 50–70%, and also a well-developed system of vapor-removal grooves located in the evaporation zone at the boundary between the wick and the wall being heated. Moreover, LHPs do not contain any mechanically movable parts and do not consume any additional energy, which allows us to refer them to the so-called "passive" heat-transfer devices, whose capacity may reach hundreds and thousands of watts. These properties open up more possibilities for using loop heat pipes, for instance, in energy-efficient systems of recovery of low-potential heat, for heat transfer from renewable energy sources, and also in systems of heating and cooling of various units remote from heat sources or sinks [2–5]. Therefore the development of long and powerful LHPs, as well as the study of their thermal characteristics, is a topical problem that attracts the attention of many researchers. To such developments may be referred, in particular, LHPs about 4 m in length with ammonia

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Nomenclature

Cp	isobaric heat capacity, J/kg K
G	mass flow rate, kg/s
d	diameter, m
h	latent heat of vaporization, J/kg
k	thermal conductivity, W/mK
K_l, K_v	figures of merit
L	length, m
p	perimeter, m
P	pressure, Pa
ΔP	pressure drop, Pa
Q	heat load, W
r	radius, m
R	thermal resistance, °C/W
Re	Reynolds number
S	area, m^2
T	temperature, °C
v	velocity, m/s

Greek symbols

δ	thickness, m
ε	absolute roughness, m
φ	slope angle, deg (°)
μ	viscosity, Pa s
ρ	density, kg/m^3
σ	surface tension, N/m
ζ	friction factor

Subscripts

c	capillary
cc	compensation chamber
cj	cooling jacket
cond	condenser
cool	cooling
ev	evaporator
out	outer
h	heater
in	inner
l	liquid
ll	liquid line
v	vapor
vg	vapor removal groove
vl	vapor line
w	wick

as a working fluid capable of transferring in a horizontal position up to 350 W at temperatures from 40 to 60 °C [6,7]. Ref. [8] presents the results of investigations of an ammonia LHP more than 2 m long transferring 1700 W in the so-called "antigravitational" regime, at a temperature of 60 °C, when the heat source was located above the heat sink. Another LHP with a length of about 3 m demonstrated the ability to transfer 500 W in a horizontal position at an operating temperature of 125 °C, which is extremely high for ammonia [9]. Ref. [10] presents the results of tests of a device about 3 m in length consisting of two ammonia LHPs connected in series, whose maximum power was equal to 800 W at a temperature of 75 °C, operating in the " antigravitational" regime with a slop angle of 60°. An LHP 10 m long was tested with ethanol as a working fluid. At a horizontal position the maximum power of the device reached 340 W at a temperature of 85 °C and a thermal resistance of 0.11 °C/W [11]. Ref. [12] presents the results of development and tests of an ammonia LHP with a length of the evaporator line of 2598 mm and an inside diameter of 4.57 mm. A maximum capacity of about 600 W was achieved at a vapor temperature of 40.3 °C when the temperature of the liquid cooling the condenser was equal to 5 °C.

The aim of the present work was the development and the investigation of the thermal characteristics of LHPs with a maximum power of no less than 1700 W capable of transferring heat in a horizontal position for a distance of 20 m at a vapor temperature at a level of 40–60 °C.

2. The choice of a working fluid and structural materials

The correct choice of a working fluid and structural materials determines considerably the heat-transfer characteristics of an LHP, their stability, and also the service life of the device. For the above-mentioned range of operating temperatures it is best to use such working fluids as water, methanol, ethanol and ammonia, which possess the appropriate thermophysical properties. The choice of a working fluid may be based on the comparison of

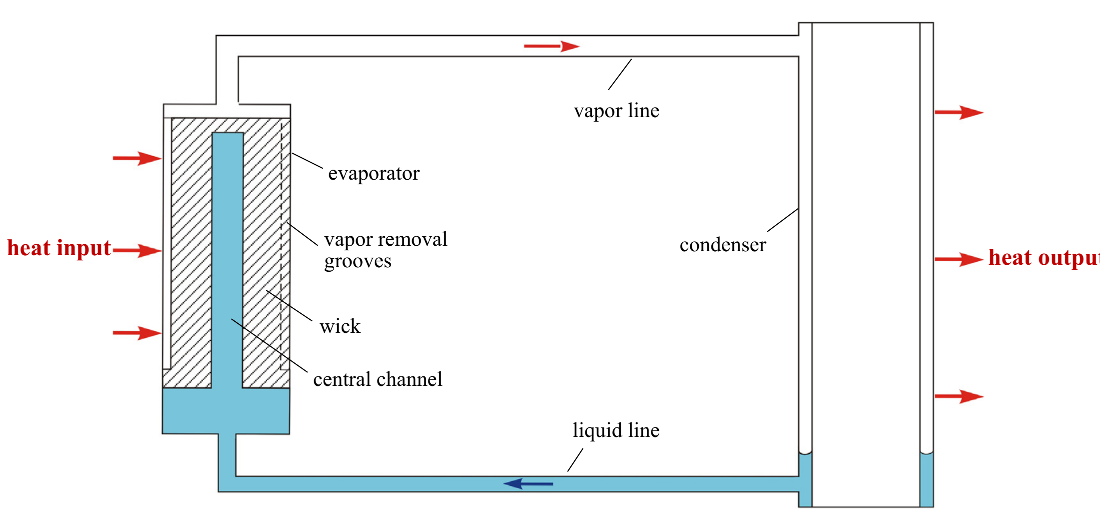

Fig. 1. Principle scheme of the LHP.