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Evaluating the possible configurations of incorporating the loop heat pipe into the air-conditioning systems

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ABSTRACT

The possible configurations of incorporating the loop heat pipe into the air-conditioning system to perform the reheat process are introduced and evaluated. The results show that the coefficient of performance of the system can be improved and the energy required by the compressor can be reduced when LHP is used instead of the heating element. For low room sensible heat factor, using loop heat pipe can improve the COP by approximately 2.1-fold over that when heating element is used. The results also show that the possible configurations of incorporating the loop heat pipe considered for small air-conditioning unit have the same COP, and among the possible configurations used in air-handling unit. The configuration where the loop heat pipe evaporator is placed in the supply air passage gives the highest COP followed by that where the loop heat pipe evaporator is placed in the return air passage then that where the loop heat pipe evaporator is placed in the passage of the outside air.

Evaluation des configurations envisageables de boucles de caloduc intégrées dans les systèmes de conditionnement d'air

Mots clés : Conditionnement d'air ; Enquête ; Caloduc ; Thermosiphon ; COP

1. Introduction

The loop heat pipe (LHP) and capillary pumped loop (CPL) are devices that allow the transfer of very substantial quantities of heat through small surface areas, and over long distances with small temperature differences and no external pumping power is needed. For instant, heat pipe can transfer 10 times the heat of pure rod with a 100 °C temperature difference (Holman, 1981).

LHP was first introduced in 1960s by scientists from Russia. At the same period Laub and McGinness (1961) from the USA began to investigate a two-phase thermal control system called a capillary pumped loop (CPL). While they only examined a capillary pumped vapor generator, their work was later expanded on by Stenger (1966) but received special attention in the late 1970s.

The basic configuration of LHP is shown in Fig. 1. It essentially comprises five components, evaporator, compensation chamber (reservoir), vapor transport line, liquid return line, and condenser. It operates passively by means of capillary forces generated on a porous structure present in the evaporation section, which is responsible for driving a working fluid

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Nomenclatures

C_p	specific heat, $kJ\,kg^{-1}$
h	specific enthalpy, $kJ\,kg^{-1}$
$\dot{m}$	mass flow rate gains, $kg\,s^{-1}$
O_3	ambient condition
Q_L, Q_s	latent and sensible heat gains, kW
$\dot{V}$	the volume flow rate, $m^3\,s^{-1}$
$\dot{W}_c$	rate of work of compressor, kW
$W_{c,a}$	power of the compressor, kW

Greeks

ΔP	pressure drop
η_e	compressor electrical efficiency
η_s	isentropic efficiency

Subscripts

a	air
C	conditions of the air leaving the coil
e	evaporator
r	refrigerant
M	mixing air condition
oa	outside air
R	return air condition
ra	return air
rh	reheat
S	supply air condition
sa	supply air

from a high temperature source to a low temperature sink (Riehl et al., 2002). A condensible fluid is contained in the loop heat pipe and when heat is added in the evaporator, the surface tension acting on the concave liquid–vapor interface causes the pressure to be higher in the vapor than in the liquid. This pressure transmits the vapor to the condenser, where it condenses and transfers back to the evaporator section through the liquid line.

The difference between LHP and CPL lies mainly in the integration of the reservoir into the loop operation. In an LHP the compensation chamber is integrated to the evaporator while in the CPL, the compensation chamber is connected to the evaporator through a piping system. This design difference results in an LHP being more robust and simpler to start (Hamdan et al., 2002).

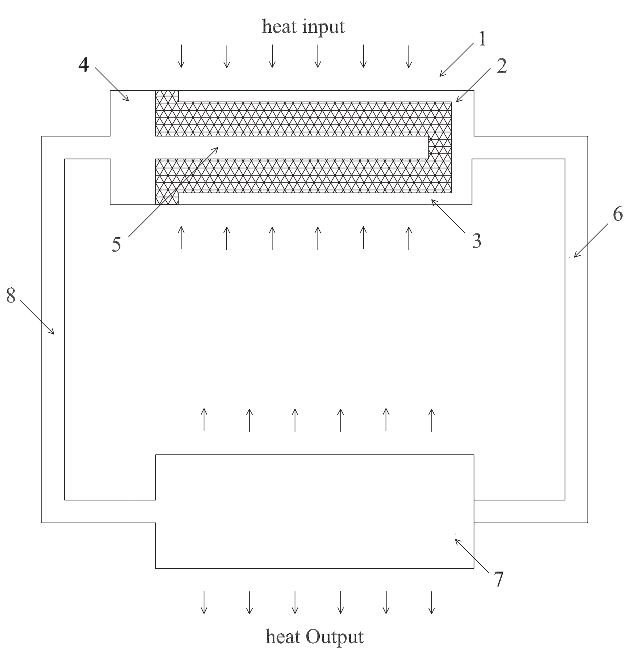

Fig. 1 – The basic configuration of the loop heat pipe, 1: evaporator, 2: capillary structure (wick), 3: vapor removal passage, 4: compensation chamber, 5: central core of the evaporator, 6: vapor line, 7: condenser and 8: liquid line.

The working fluid circulated in these devices should have certain desirable characteristics (Mills, 1999). Those include a high latent heat of vaporization so that large quantities of heat may be transferred with a minimum fluid flow rate. The surface tension of the fluid should be high so that adequate evaporator pressure differences can be obtained. The vapor density should be as high as possible to keep vapor velocity, and thus vapor pressure drop to a minimum. A low vapor viscosity is also favorable to reduce the vapor pressure drop. Also the working fluid should have a high thermal conductivity to reduce the temperature drop in the condenser and evaporator (Dunn and Reay, 1982).

The selection of the wick for the heat pipe depends on many factors. The wick structure must have a small pore size to generate a capillary pressure. Compatibility and wettability of the working fluid with the wick are other necessary properties the wick must have.

While loop heat pipe and conventional heat pipe have the same principle function of transferring heat energy from one location where it not desired to another location where it can be rejected, the arrangement of their components is different. While in the LHP, the wick is limited to the evaporator section, the evaporator, condenser and the liquid return line of the conventional heat pipe are all covered with the wick structure. The advantage of LHP over the heat pipe is that because the wick is limited to the evaporator, it is possible to use capillary structure with quite small pores. Such pores can creates a capillary pressure of tens kilopascals (Maidanik, 1993). Also, because the vapor and liquid lines of LHP do not have wicks, the pressure drops are reduced along these lines, allowing for larger mass flow rates under the capillary pumping limit (Dickey and Peterson, 1994). Unlike heat pipe, LHP provides thermal isolation between the vapor and the liquid (Liepmann, 2001).

Heat pipe and loop heat pipe have found many varied uses in both spacecraft and land based applications. Those include controlling the temperature of an entire spacecraft payload (Parker, 2000), thermal control of electronic components such as high power semiconductors and computer cooling (Pastukhov et al., 2003; Pastukhov and Maydanik, 2007), and solar collector (Mettawee and Assassa, 2006; Riffat and Zhao, 2004).