



Research paper

Adsorption-based antifreeze system for loop heat pipes



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H I G H L I G H T S

- A tank containing an adsorbent is associated to a LHP to protect it from freezing.
- This storage tank enables the use of water as the working fluid of the LHP.
- Several configurations are proposed for this association.
- Simulation results show that the storage tank volume is acceptable.
- Simulation results show that the power required by the system is moderate.

A R T I C L E I N F O

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A B S T R A C T

The use of water in loop heat pipes (LHP) is known to be desirable: water is almost freely available; it exhibits high thermal performance and is non-toxic. Nevertheless, water has a major drawback which is its anomalous expansion when cooled down to a negative temperature. This is likely to damage the capillary wick of the LHP. To overcome this problem, a storage tank may be coupled to the loop heat pipe. It contains a strong adsorption capacity material designed to adsorb the fluid during shutdown phases of the system and to desorb it during the startup phases. A storage tank using the RD-type silica gel as adsorbent material was designed. It is a passive system, which does not require mechanical elements to circulate the fluid and does not degrade the thermal performance of the device. However, a secondary auxiliary heating system is required to desorb the fluid. Furthermore, it may be located away from the heat source and it is compact. The simulation results show that the storage tank volume is acceptable and requires moderate energy to desorb the fluid.

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1. Introduction

Heat pipes and thermosiphons are efficient heat transport devices mainly made up of an evaporator and of a condenser, and widely used in various applications, like solar energy [1–3], space technologies [4,5], electronics cooling [6], nuclear [7], heat exchangers [8], etc. Among them, Loop Heat Pipes (LHP) enable the transport of high amounts of thermal energy along separated vapor and liquid lines, reducing the friction forces compared to the conventional heat pipes. In LHPs, the evaporator contains a porous structure, inducing a higher pumping pressure than in thermosiphons. The passive fluid circulation, induced by the capillary pressure in the porous medium, as well as the use of latent heat of vaporization enable the transport of high amounts of thermal energy, even against an adverse gravity field. These two-phase

systems were developed in the 1970's in the Soviet Union and they have already proven their reliability and high performance in numerous space applications. They are highly efficient contemporary candidates for terrestrial applications, such as aeronautic and automotive industries. In the last decade, many investigations were undertaken in order to further develop these systems and to improve them *i.e.* to increase their flexibility, efficiency, reliability and possibility of implementation in existing architectures ([9–12]). For example in Ref. [13], a LHP was designed in order to cool electronic components embedded in civil and military avionic equipment. The use of water as working fluid was envisaged in this device because of its numerous advantages: it is almost freely available, it exhibits high thermal performance and it is non-toxic. In this kind of applications, the working fluid is subjected to temperatures between 0 °C and 100 °C. Conversely, when the LHP is at shutdown, the device can be subjected to freezing temperatures. Below 0 °C, water expansion is likely to damage the capillary wick or the liquid line of the LHP.

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Nomenclature*List of symbols*

A	cross-section m^2
c	specific heat capacity $\text{J kg}^{-1} \text{K}^{-1}$
h	heat transfer coefficient $\text{W m}^{-2} \text{K}^{-1}$
l	length m
m	mass kg
P	pressure Pa
p	perimeter m
Q	thermal energy J
q	adsorption capacity $\text{kg of refrigerant/kg of dry adsorbent}$
T	temperature K
V	volume m^3

Greek letters

λ	thermal conductivity $\text{W m}^{-1} \text{K}^{-1}$
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ρ	density kg m^{-3}
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Subscripts

ads	adsorption
amb	ambient
C	condenser
cc	compensation chamber
cp	connecting pipe
G	vapor grooves
L	liquid line
l	liquid
LHP	inside the LHP
max	maximum
min	minimum
sg	silica gel
V	vapor line
v	vapor
w	water
wi	capillary wick

Various solutions were suggested in the past to overcome the drawbacks related to the water solidification, when it is subjected to sub-freezing temperatures. In many engineering objects, an antifreeze mixture is added to water to prevent ice formation below 0°C . Nevertheless, the use of binary fluids in heat pipe is not suitable because of the serious reduction in their efficiency under such conditions. In order to partially compensate the increase of the liquid volume when it solidifies, the use of suspended nanoparticles was proposed by Sarno and Tantolin [14]. These particles have the ability to bear a certain compression during solidification, thus limiting the overall effect of expansion of the liquid. Nevertheless, it is likely that these particles will not be drained with the vapor. They may rather get accumulated in the wick in working conditions, thus degrading the performance of the LHP and limiting their effects to the wick and not the liquid line.

This article deals with a novel system, using an adsorption material as described in Ref. [15], that was proposed to face the issue of freezing of water in LHPs. Adsorption is the physical process through which molecules of a fluid called adsorbate are fixed onto the surface of a porous solid, called adsorbent. There are two kinds of adsorption processes: physisorption (or physical adsorption) and chemisorption (or chemical adsorption). In the case of physical adsorption which is of interest in the present work, interactions between the adsorbent and the adsorbate of electrostatic nature, mainly due to Van der Waals forces. These interactions are weak and reversible. This is why the adsorbed molecules can be easily desorbed by reducing the pressure or increasing the temperature. As a matter of fact, adsorption is an exothermic process and is favored by low temperatures. Conversely, desorption is an endothermic process and is favored by high temperatures. The principle of adsorption was already used in some applications of heat pipes ([16,17]), in order to enhance the heat transfer intensity in the porous evaporator using a sorbent bed.

We consider a storage tank which contains an adsorbent material and that is connected or embedded in a LHP. At low temperatures, during shutdown phases of the LHP, the adsorbent material has the ability to adsorb significant amounts of water. Removing the vapor from the capillary wick and the liquid line constitutes a method to protect the LHP against freezing. On the contrary, during startup phases, the material adsorption capacity decreases due to the temperature increase. Part of this fluid is thus desorbed and enters the LHP, enabling its effective operation. This device does not

require mechanical elements to circulate the fluid since the fluidic movements are carried out by the sorption phenomena. In addition, the desorption process can help the LHP startup. The aim of the present article is to prove the feasibility of this newly proposed system, to design it, to determine its dimensions, its operational temperature and the energy that has to be supplied for its operation.

2. Operating principle of the adsorbent storage tank

Several solutions are proposed to add the adsorbent storage tank to a LHP:

- 1/ The first configuration consists in creating a by-pass of the evaporator-reservoir assembly, where the adsorbent storage tank is connected to the LHP by means of a connecting pipe between the liquid and the vapor lines (Fig. 1). Three valves and a thermal link between the storage tank and the evaporator are required to enable the operation of the device.

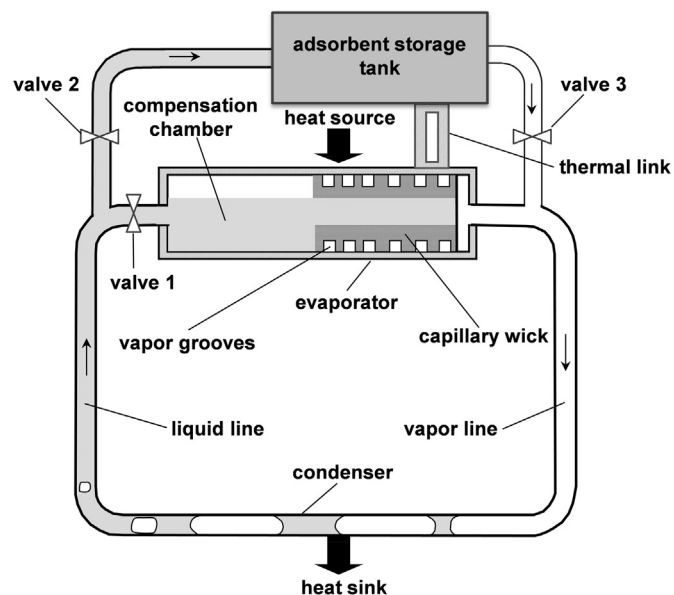


Fig. 1. Schematic of the device with valves and a thermal link.

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