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A review of loop heat pipes for aircraft anti-icing applications

Qian Su[a], Shinan Chang[a,*], Yuanyuan Zhao[a], Haikun Zheng[a], Chaobin Dang[b]

[a] School of Aeronautic Science and Engineering, Beihang University, Beijing 100191, China
[b] Institute of Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, 5-1-5 Kashiwanoha, Kashiwa, Chiba 277-8563, Japan

HIGHLIGHTS

- The application environment of the loop heat pipe ice protection system (LHPIPS) is described.
- The fundamental design of the LHPIPS is introduced.
- A series of optimization strategies regarding the LHPIPSs are proposed to enhance their operating performance.
- The feasibility and practicability of utilizing the LHPIPS for aircraft anti-icing have been proved.

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ABSTRACT

Loop heat pipes (LHPs) are highly efficient two-phase heat transfer devices with the ability to transport significant amounts of heat over long distances. Owing to the increasing demand of anti-icing applications in aircraft, certain investigations regarding LHP anti-icing have been successfully conducted, which verified the anti-icing capacity and feasibility of loop heat pipe ice protection system (LHPIPS). In this work, we will conduct a deep analysis on the LHP application to aircraft anti-icing. After a brief introduction of the historical application background and application environment of the LHPIPS, a detailed description of its fundamental design will be elucidated, followed by a series of optimization strategies, including the graphene-coating integration technology, the adoption of bidisperse wicks, the introduction of nanofluids, and the use of double compensation chamber loop heat pipe (DCCLHP). We present the additional points that require further study and that could be further optimized for the development of the LHPIPS. This work contributes to a thorough understanding of the novel and promising LHPIPS, as well as guides its future designs and applications.

Contents

Abbreviations: LHP, loop heat pipe; SFC, specific fuel consumption; LHPIPS, Loop heat pipe ice protection system; CIPS, conventional ice protection system; DCCLHP, double compensation chamber loop heat pipe; UAV, unmanned aerial vehicle; CC, compensation chamber; 3WV, three-way value; DLHP, distribution loop heat pipe; CPUs, Central processing units; TLHP, transportation loop heat pipe; TCV, thermal control valve; HPs, heat pipes; HTC, heat transfer coefficient; CPL, capillary pumped loop.

* Corresponding author.
E-mail address: sn_chang@buaa.edu.cn (S. Chang).

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1. Introduction

Emerging as a versatile and promising heat transport device, the loop heat pipe (LHP) utilizes the capillary action generated by a porous wick to implement the evaporation and condensation cycles in the sealed enclosure. A traditional LHP (Fig.1) consists of an evaporator, a condenser, a compensation chamber (CC), and a vapor/liquid line. The operation of the LHP involves multi-scale mechanisms, as shown in Fig.1. LHPs possess all the main advantages of the traditional heat pipes (HPs) with additional characteristics, such as higher heat transfer efficiency, long heat transport distances, insensitivity to adverse orientations, and design flexibility.

The quick evolutions of compact electronic packaging and miniaturization technology promote the development of LHPs, which have rapidly gained recognition as highly efficient heat transfer devices for thermal control applications in various fields, from aerospace [2–4] to terrestrial industries [5]. As for the field of aerospace, the appearance of LHPs is a response to the challenge associated with the demand for high heat dissipation [6,7]. LHPs are used to remove excessive waste heat that is released from the heat source (e.g., electronic units) and transfer it to the heat sink (e.g., deployable radiators) to maintain the temperature of the heat source within certain reasonable ranges. The flight testing of an LHP model aboard the Columbia Space Shuttle is a successful case of LHP application for spacecraft thermal management [8]. Until now, several LHPs have been mounted on satellites to examine their operating behaviors; the results revealed their reliability and long-term operation under micro-gravity conditions. With regards to ground-based applications, LHPs are employed for the cooling of high-speed central processing units (CPUs) in computers [9,10] and airborne electronics [11,12], to control the temperature of electronics.

Generally, LHPs are used to cool electronic equipment both in aerospace and ground applications, extending their applications for aircraft anti-icing opens a new direction. Some investigations regarding LHP anti-icing have been successfully conducted and corresponding investigations have illustrated its feasibility [13–19]. A loop heat pipe ice protection system (LHPIPS) is an integrated thermal management technology that effectively utilizes the waste heat generated aboard the aircraft for anti-icing purposes without additional power input (exhibiting significant energy-saving gains over the conventional ice protection systems (CIPS)) and provides cooling for the systems which produce excessive waste heat.

Review studies and further experimental works on the application of LHPIPSs in aircraft are limited, compared with those on the LHPs. There is still ample room for improvement in this area.

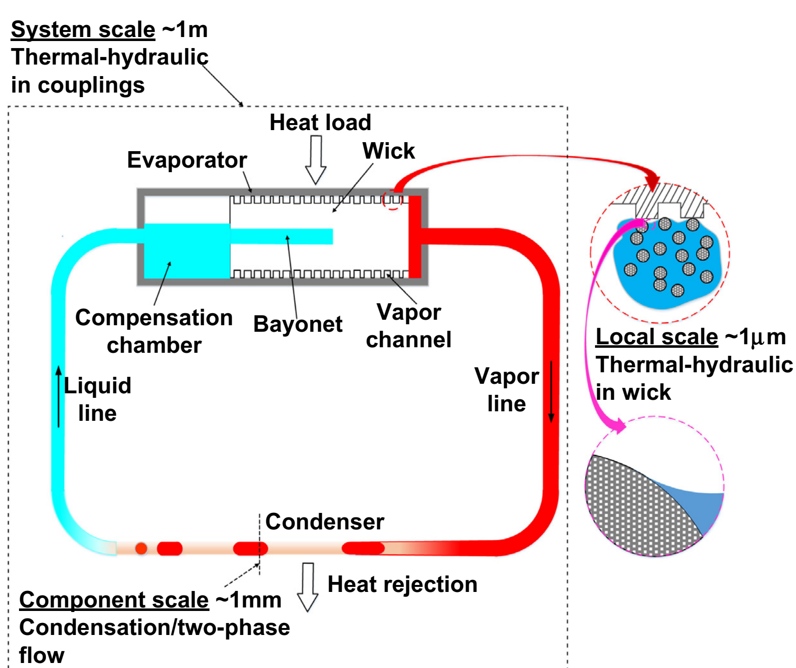

Fig. 1. Schematic of the LHP [1].