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# Experimental study of capillary pumped loop for integrated power in gravity field

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ABSTRACT

Year after year, thermal dissipation due, for instance, to power electronics, is increasing. The efficiency demand is consequently growing for highly efficient cooling systems as classical solutions are becoming outdated. In this context, Capillary Pumped Loops (CPLs) appear as innovative and efficient heat transfer devices but there is still a lack of data concerning their operating characteristics in gravity field for terrestrial applications. Thus, in this work, a particular design of CPL (called CPLIP) with flat evaporator, designed by the Euro Heat Pipes society in Belgium, has been tested at steady state and transient regime in order to provide data and new insights into thermal and hydraulics couplings of these systems.


## 1. Introduction

For some years, terrestrial transport applications, such as the French high speed train ("TGV"), have shown a great increase of heat dissipated by power electronics, for instance. Conventional cooling devices like single-phase loops and even nucleate boiling have reached their limitations. Fortunately, two-phase heat transfer devices appear as the possible next step for power electronics cooling in such applications [1,2]. For almost fifty years, Capillary Pumped Loops (CPLs) and Loop Heat Pipes (LHPs) have been developed and tested for space applications such as NASA's GLAS [3], CNES's STENTOR [4] and ESA's COM2PLEX [5], among many others [6–10]. The CPL, designed by Stenger in 1966 [11], has been mostly developed in United States and Europe whereas LHP appeared in Russia almost at the same time [12] with the work of Gerasimov et al. [13]. However, conceptually, CPLs and LHPs remain very similar. Both can be divided into three major components: evaporator, condenser and reservoir. These parts are connected with bendable pipes forming a loop between dissipative and cooling areas. It allows to set up condenser at a specified position regardless of dissipated heat location.

As pointed out by Nikitkin and Cullimore [14], the main difference between LHPs and CPLs is the reservoir position in regards to the evaporator. A CPL's reservoir is located on the liquid line and is thermally separated from the evaporator whereas a LHP's reservoir is side by side with the evaporator. A secondary wick between the evaporator and the reservoir makes this thermal link even stronger for LHPs [14]. Thus, Startup is easier for LHPs but their behaviour remains less secure thereafter. CPLs need reservoir preconditioning for startup and their operating temperature can be controlled during operation which is an interesting functionality for power electronics cooling. According to Nikitkin and Cullimore, any middle design between CPL and LHP can be proposed.

Depending on the wick efficiency, LHPs and CPLs are able to transfer heat over long distances and even produce a capillary pressure rise exceeding the gravitational losses in the loop. That is why it is challenging to adapt these devices to applications involving gravity field. Thus, Euro Heat Pipe society (EHP, based in Belgium) has designed a "Capillary Pumped Loop for Integrated Power" (CPLIP) in order to respond to the increasing demand for efficient heat transfer devices in terrestrial applications. This design is illustrated in Fig. 1(a). This work will focus on the experimental analysis of operating characteristics and thermohydraulics couplings of the CPLIP during steady state and transient regimes. One major originality of this study is the presence of flowmeters on the loop lines allowing to perform a detailed hydraulic analysis of the CPLIP operation.

Joung et al. [15] have also recently studied a flat evaporator CPL with reservoir located above the evaporator. Their "FECPL" design remains the most alike to the CPLIP among other CPL configurations that can be found in literature [16–19]. Yet the CPLIP dimensions are far greater as will be detailed later. Then, contrary to Joung et al. CPL, the CPLIP reservoir is divided into two parts with liquid flowing through the lower part (Fig. 1(a)). Finally, evaporator design is particular (with inner design as property of EHP) and its height is sufficient to consider gravity effects inside evaporator during

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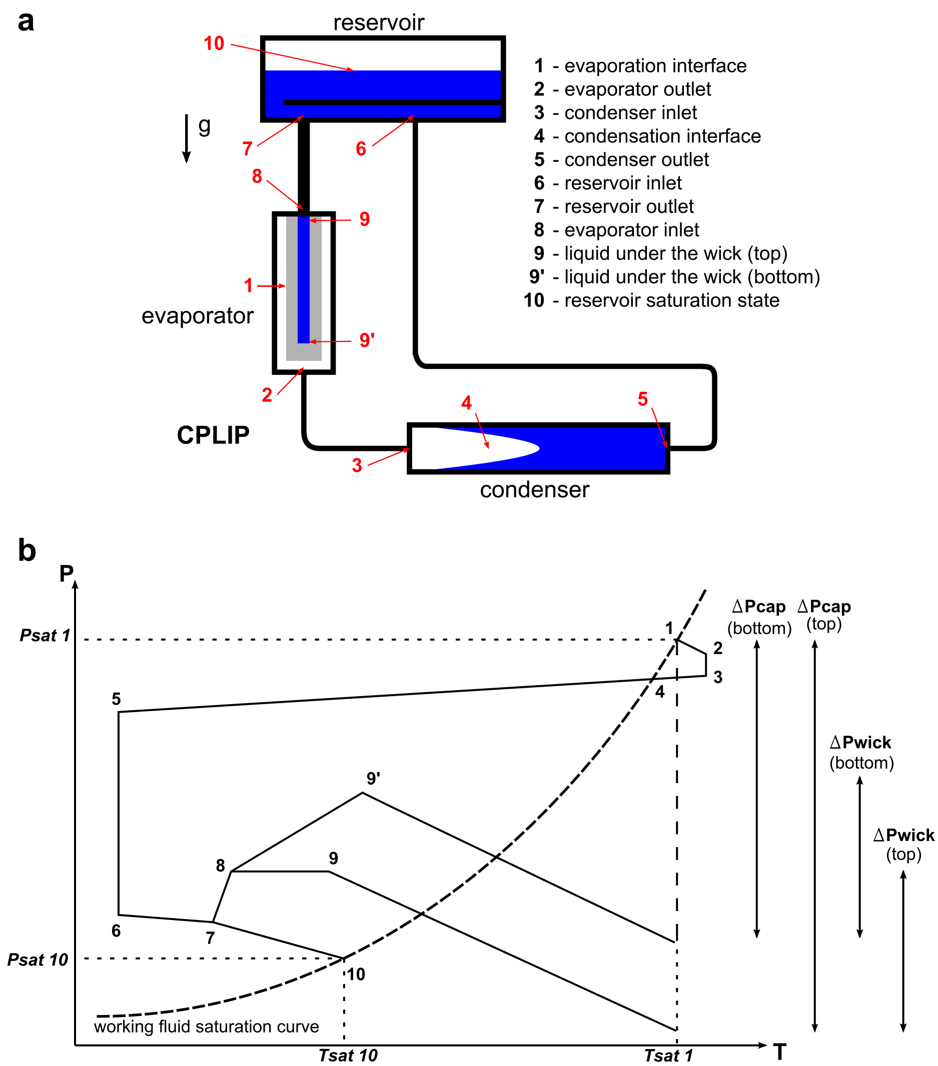


**Fig. 1.** CPLIP design by EHP (a) and pressure/temperature diagram of its operation (b).

operation. Despite the differences between CPLIP and Joung et al. FECPL, these systems are similar enough to allow an interesting comparison between both studies.

## 2. Operating principles

The CPLIP operation is described in the Pressure/Temperature diagram of Fig. 1(b) with respect to CPLIP design of Fig. 1(a). Lines are supposed completely insulated in this operating case. Heat power is applied at the evaporator where the saturation interface is located at point 1. The produced vapour flows through vapour grooves to the evaporator outlet (2), inducing pressures losses $\Delta P_{1-2}$ and superheat $\Delta T_{1-2}$ of Fig. 1(b). The vapour then flows to the condenser inlet (3) inducing pressure losses $\Delta P_{2-3}$. After condensation (4) and liquid subcooling (4–5), the liquid flows through liquid line to reservoir inlet (6). The pressure drop $\Delta P_{5-6}$ is a combination of frictional pressure losses in the line and gravity pressure drop due to height difference between the condenser outlet (5) and the reservoir inlet (6). Liquid flowing through the lower part of reservoir (6–7) is then heated, due to heat transfer between the two reservoir parts ($\Delta T_{6-7}$). The pressure difference $\Delta P_{7-8}$ is a combination of gravity pressure drop and frictional pressure losses in the line between reservoir outlet (7) and evaporator inlet (8). The liquid heating $\Delta T_{7-8}$ is due to heat conduction from the evaporator body through the pipe. The liquid in the evaporator artery can then enter the wick between the top (9) and the bottom (9′) of the evaporator. The pressure difference $\Delta P_{9-9'}$ is almost equal to gravity pressure drop due to height between 9 and 9′. Finally, the liquid flows through the wick to the evaporation interface (1) with pressure losses $\Delta P_{wick}$ shown in Fig. 1(b).

It is interesting to note that the CPLIP keeps one major operating characteristic of CPL: the operating temperature controllability by the reservoir. As shown by Eq. (1):

$$T_{sat,1} = f(P_{sat,1}) = f(P_{sat,10} - \Delta P_{1-10}) = f\left(f^{-1}(T_{sat,10}) - \Delta P_{1-10}\right) \quad (1)$$

and Fig. 1, the reservoir high part saturation state (10) is the reference point of CPLIP working cycle. In Eq. (1), $f$ is the saturation function of the working fluid and $\Delta P_{1-10}$ the amount of pressure losses and drops between the vapourisation interface and the higher part of reservoir, which is set by CPLIP design. Therefore, it appears clearly that controlling the reservoir saturation temperature $T_{sat,10}$ directly impacts the saturation temperature in the evaporator ($T_{sat,1}$). This functionality is particularly interesting in