

Satellite Thermal Control: Cooling by a Diphasic Loop

L. Boukhris, A. Boudjemai, A. Bellar, R. Roubache, and M. Bensaada

Abstract— In space during functioning, a satellite will be heated up due to the behavior of its components such as power electronics. In order to prevent problems in the satellite, this heat has to be released in space thanks to the cooling system. This system consists of a loop heat pipe (LHP), in which a fluid streams through an evaporator and a condenser. In the evaporator, the fluid captures the heat from the satellite and evaporates. Then it flows to the condenser where it releases the heat and it condenses. In this project, the two main parts of a cooling system are studied: the evaporator and the condenser. The study of the diphasic loop was done starting from digital simulations carried out under Matlab and Femlab.

Keywords— capillarity, condenser, evaporator, phase change, transfer of heat.

I. INTRODUCTION

THE heat transfers with phase change in a porous environment are presented in the fields of the nuclear power, oil, geothermic or space industries. We will present here a modern and powerful technology of cooling, using an innovating evaporator: a porous wick.

It is more particularly for the cooling of the satellites than we will study this system comprising a diphasic, called Loop Heat Pipe or buckles heat pipe.

The diphasic loop, simply illustrated of figure 1, is composed of an evaporator, a condenser, a tank of coolant and possibly a pump [1], [2]. In the case of this study, one uses ammonia as coolant because of its properties. It is light and especially, it does not freeze in the conditions of temperature and pressure of space.

The principle of operation is to evacuate in space the heat produced by the satellite by vaporizing ammonia in the “hot part”: the evaporator. The configuration of this evaporator allows the pumping of the liquid by capillarity while separating the phases liquid and vapor for better conditions from evaporation. A porous wick pumps the fluid which runs out then in the conduits. A pocket vapor is then formed in the porous environment according to a liquid interface/gas characterized by stable menisci in the pores.

On the outlet side of the evaporator, the vapor runs out towards the “cold part”: the condenser, where heat is evacuated towards outside and the liquid Re-digest.

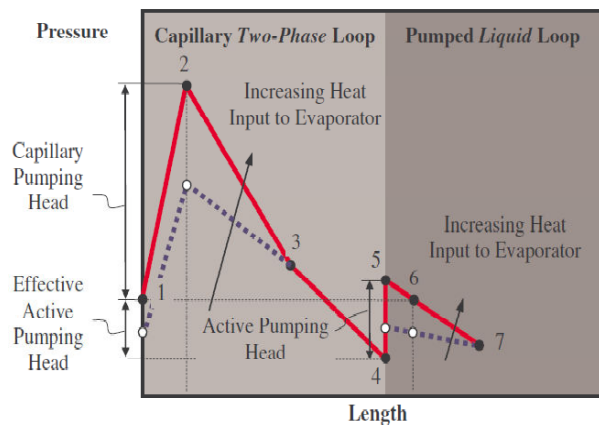
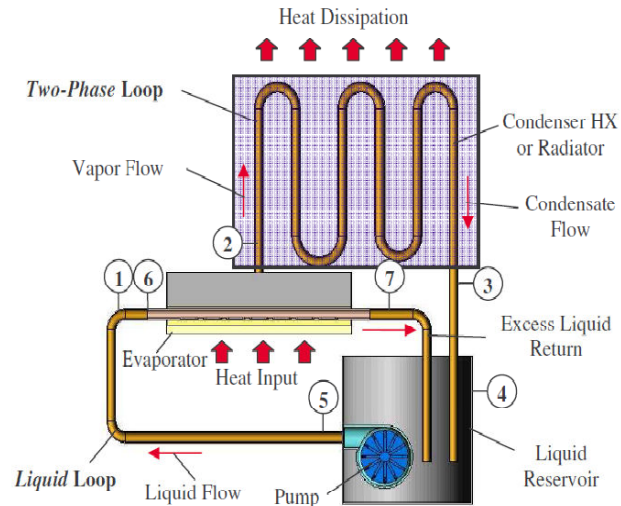


Fig. 1 Diagram of the cooling loop

The phenomenon of capillarity is at the base of this system, the liquid advances in the evaporator, which vaporizes in the porous wick. The wick automatically controls the flow of the liquid and the vapor thanks to the menisci and with the capillary pressure: the jump of pressure through a meniscus. The heat brought to the evaporator increases the temperature of the system, which causes then the evaporation of the liquid coolant. The generated vapor is then conveyed, thanks to the difference in pressure, to the condenser, then with the tank. The maximum heat flow evacuated will be limited by the capillary capacity of the porous wick of the evaporator from where the addition or not of a pump. Thus, we will study the evaporator, its operation according to the heat flow which will be evacuated, and need or not for a mechanical pump.

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- The studied diphasic loop is made up of various elements:
- An evaporator, located inside the body of the satellite,
 - Two spreadable radiators located on the walls North and South of the satellite (see figure 2),
 - A mechanical pump, located towards the entry of the evaporator.

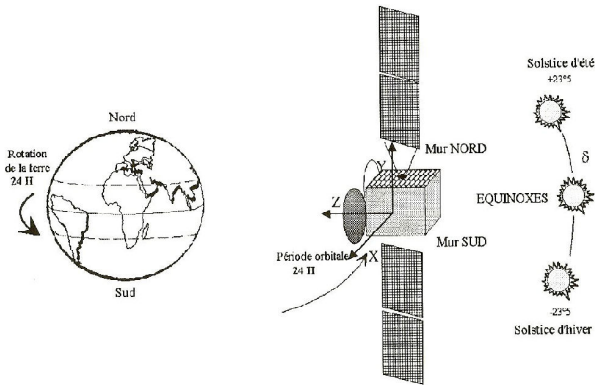


Fig 2 Position of the satellite compared to the ground and to the sun, extreme cases

The scheme illustrated above shows the provision of the diphasic loop (figure 3). It should be noted that the two radiators are dissymmetrical. The two radiators are separated by a distance from three meters, which involves a light difference in pressure between the entry of the first radiator and that of the second.

This configuration is more complex than a provision series of the two radiators (provision retained for the continuation of the study).

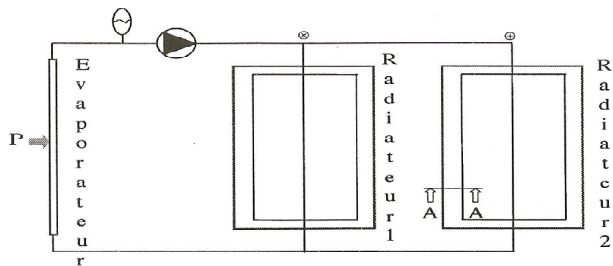


Fig. 3 Scheme of the diphasic loop

II. THE EVAPORATOR

At the entry of the evaporator, the ammonia is in a monophasic state and between supercooled because its temperature is lower than the temperature of saturation. Progressively of its evolution in the evaporator, the fluid is heated by the external flow of heat and it reaches its temperature of saturation. A nucleate boiling is thus created in wall. One is then in a flow pattern to bubbles [3].

At this moment, the rate of vacuum in the flow does nothing but grow. Of a configuration “Pocket-Stoppers”, one leads to a qualified configuration of annular flow since there remains only one film of liquid throughout the wall.

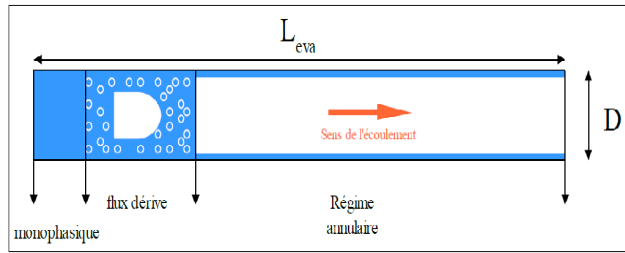


Fig 4 Flow in the evaporator

The choice of the model for each step of space located in diphasic zone was based on the criterion of maximization of the rate of vacuum. Thus, in each point of the evaporator, the rate of vacuum is calculated by the model with flow of drift and by the model with annular flow, and the model selected is that giving the greatest value [3].

For each of the two models, the figure above presents the evolution of the rate of vacuum in the zone of evaporation, according to the vapor quality, for a flow of 5 g/s. One can notice that the model with flow of drift has an asymptote with 0.8 while the other models tend towards 1. In addition, a vapor quality of transition gets clear. It is worth approximately 0.12. Below this value, the difference between the two models is tiny. Beyond 0.12, the variation is significant. Throughout this work we can conclude as for the choice from the diphasic model of flow. Beyond the vapor quality of transition, the model with two fluids must incontestably be privileged because the model with drift flow is not valid any more. Below the vapor quality of transition, the two models appreciably give the same rate of vacuum.

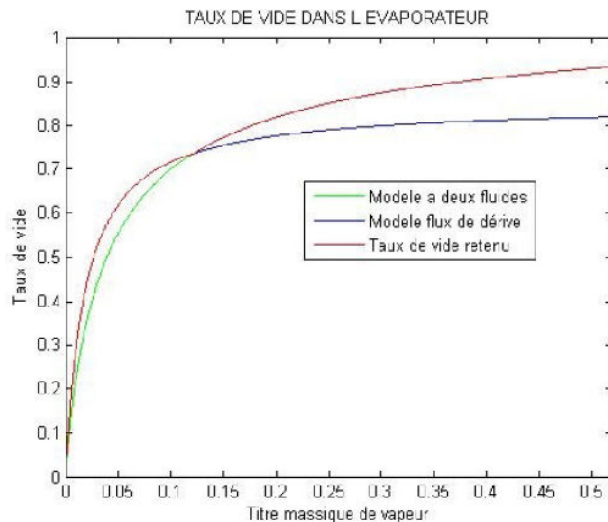


Fig. 5 Rates of vacuum calculated by the various models, in the evaporator

III. THE RADIATOR

The fluid enters the radiator in annular flow, and since, with the outside heat transfer, it cools (the outside temperature is taken in the two extreme cases: 220 K and 4 K). The flow goes then transit in flow pocket-stoppers for finally passing in

monophasic flow as soon as the temperature of the fluid becomes lower than its temperature of saturation [4].

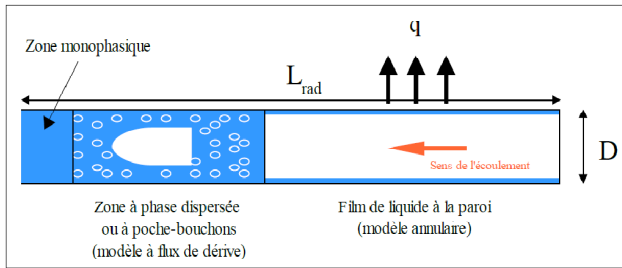


Fig. 6 Flow in the radiator

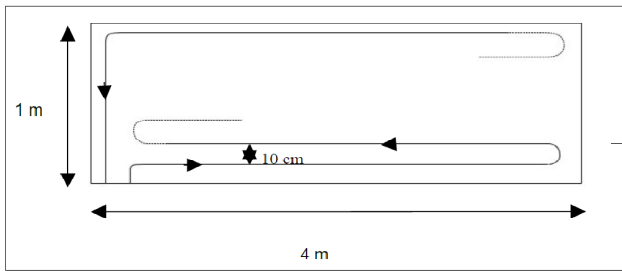


Fig. 7 Internal radiator configuration

This configuration of the tubes indeed makes it possible to minimize the number of elbow, which causes to reduce the pressure losses.

We considered a cut of radiator to be able to evaluate the heat flow emitted in the two extreme cases (Text = 4K or 220K).

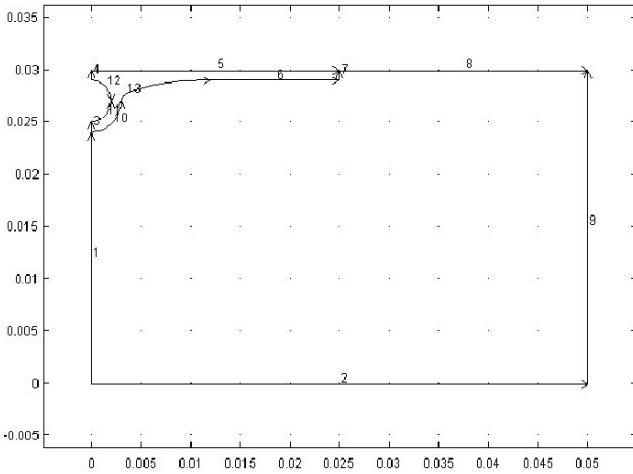


Fig. 8 Geometry of a section of tube

The radiator is composed of two materials: an aluminum tube and a wing in order to evacuate the most heat, and a honeycomb to isolate from the possible external and internal thermal contributions with respect to the satellite.

Only one half of tube and wing were considered because of the symmetry of the structure.

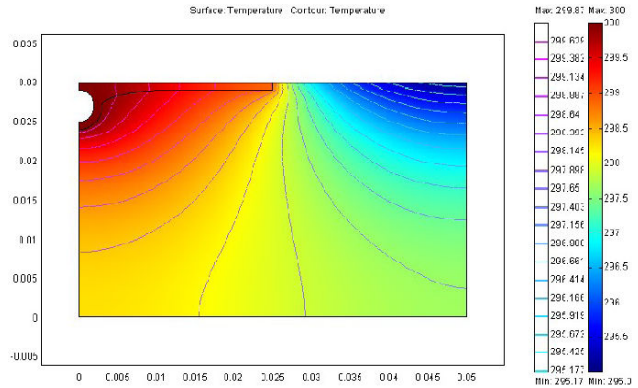


Fig. 9 Field of temperature for a diameter interns of tube of 4 mm, an outside temperature of 4 K, and a temperature of wall of 300 K

This field comforts us in the idea that the maximum of heat will be evacuated by the wing. Moreover, one sees that the distance of 10 cm imposed between each tube (see figure 7) is enough so that the tubes do not exchange too much heat between them.

IV. CONCLUSION

We set up a program allowing us to model the behavior of a diphasic loop with capillary pumping. A programming under Matlab enabled us to optimize this loop.

The major achievements from this work are summarized as follows.

- Advanced Hybrid Cooling Loop Design
- High Heat Flux Capability. The hybrid cooling loop using single planar evaporator with sintered wick design managed high heat flux. A much higher heat flux could be very likely achieved considering the system temperature results.
- Large Cooling Surface Capability: The innovative evaporator with a large planar surface area provided an excellent passive liquid management and phase separation for the best boiling condition. The evaporator design is easily transferable to high performance cooling applications requiring much larger area and various form factors.

For better understanding the behavior of the diphasic loop of cooling it is preferable to have rigorous experimental tests and numerical analysis with simpler systems with one or two evaporators.

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