# SELENE Experiment on ISS

**Roberto Di Paola[1], Yoshiyuki Abe[2], Kotaro Tanaka[3], Masahide Sato[4] and Raffaele Savino[1]**
**1 Univ. Naples Federico II, Naples Italy**
**2 AIST, Tsukuba**
**3 Shibaura Inst. Tech., Tokyo**
**4 Utsunomiya Univ., Utsunomiya**

**Abstract**

This paper presents the main purpose of an experiment that has already been accepted by European Space Agency (ESA), titled "SELf-rewetting fluids for thermal ENErgy management in space" (SELENE). For better understanding of the liquid distribution and the heat transfer mechanisms of the particular fluids in heat pipe applications, the detailed fluid dynamic and thermal behaviors in model heat pipes will be studied in microgravity condition. Rectangular transparent fluid cells have been projected in order to study more relevant effects in the inner of typical groove heat pipe in microgravity environment avoiding gravity effects.

## Introduction

Increase in size of space platforms and future exploration missions will require a large amount of heat to be dissipated by large space radiators. Efficient thermal control in space by two-phase closed-loop systems becomes of crucial importance in these devices. The present study is focused on the understanding of the heat transfer mechanism of binary or multi-component heat transfer fluids with particular surface tension behavior, the so-called "self-rewetting fluids", *i.e.* liquids with a surface tension increasing with temperature and concentration of less volatile component.

The present project intends to contribute to the understanding of the basic fluid dynamic and physicochemical mechanisms that occur in these multi-component two-phase systems, and particularly on the interplay between heat transfer and surface and bulk thermophysical properties. To pursue the above objective, the behavior of non-isothermal self-rewetting liquids will be experimentally investigated in transparent model heat pipe systems under microgravity conditions of the ISS.

Microgravity offers the opportunity to avoid gravity effects and to analyze, in detail, typical flow patterns occurring only in the space environment in relatively large systems, offering the opportunity to perform systematic experimental investigations of the processes, considering a large number of experimental conditions typical of space and terrestrial heat pipes. The experiments in microgravity allow to avoid undesired buoyancy and hydrostatic pressure effects in liquid and in vapor phase and to study only surface tension-driven effects which are essential for almost all the heat transfer devices based on two-phase flow and capillary effects. The experiments require very long duration, therefore scientific and technological results can be obtained only on the ISS using a dedicated test container.

Science team and their roles are as follows:

**Univ. Naples** (Savino): Numerical modeling, identification of experimental conditions and set-up, identification of requirements

**ULB** (Kabov & Van Varenbergh): Stability of surface properties, Material compatibility test between liquid and materials, Diagnostics requirements for evaluation of distribution of liquid and surface reconstruction (film shape and thickness measurements with interferometric techniques)

**AIST** (Abe): Support to DIAS activities and industrial applications to flat heat pipes and vapor chambers for electronics cooling

**Utsunomiya Univ**. (Sato): Nanofluids characterization, wetting test with different fluids and materials, hydrophobic/hydrophilic coatings

**Shibaura Inst. Tech**. (Tanaka): Concentration measurements with intrusive and optical techniques

**Univ. of Toronto** (Kawaji): Flow visualization and velocity measurements, and applications to oscillating heat pipes

**MARS** (Castagnolo): Breadboards development and support to definition of scientific requirements, in particular, surface temperature measurements

**EPFL** (Thome): Numerical simulations

**ENEA** (Celeta): Applications of self-rewetting fluids to loop heat pipes

## Detailed Objectives

The experiments intend to investigate, with onboard available optical diagnostics and other intrusive sensors, the physicochemical mechanisms occurring in different heat pipes systems, *e.g.* conventional cylindrical or flat

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heat pipes for terrestrial applications, as well as in thin ultra-light heat pipe radiator panels for potential space applications. Main physicochemical mechanisms that shall be investigated include:

1) Surface tension-driven and Marangoni flows induced by evaporation, condensation, temperature and concentration gradients
2) Two-phase flow and liquid and vapor distribution
3) Influence of the vapor temperature and pressure
4) Influence of the length of the evaporator and/or condenser regions

In particular, simple scaling analysis based on the assumption that the friction pressure losses in the channel are balanced only by the capillary pressure suggests that the maximum dimensionless heat flux at the evaporator/condenser (scaled with reference thermophysical fluid properties) is proportional to the square of the groove depth to length ratio (w/*L*):

$$\frac{Q}{(L/w)(\rho \mathrm{H}_v \sigma / \mu)} \propto \left(\frac{w}{L}\right)^2$$

where $Q$ is the heat flux density (W/m$^2$), $\rho$, $\mathrm{H}_v$, $\sigma$ and $\mu$ are the density, the latent heat of vaporization, the surface tension and the viscosity, respectively.

The target of the present study is to model and analyze the evaporation/condensation driven flow in heat transfer devices with maximum heat flux density of the order of 100 W/cm$^2$ and w/L in the order O($10^{-2}$), respectively.

The fluid behavior shall be investigated under different heating conditions (corresponding to different heat power density levels applied to the evaporator section) until dry-out limit is reached. The same experiments shall be carried out sequentially in different cells partially filled with different working liquids, including water as reference single-component and a number of different self-rewetting fluids, brines and nanofluids with self-rewetting propety.

Main required measurements include:

1) Heat input provided at the evaporator section
2) Heat output reduced at the condenser section
3) Temperature distributions along the liquid-vapor interface and in the liquid at different positions along the cell (TBD), from the evaporator to the condenser
4) Concentration distribution in the liquid at different positions along the cell (TBD), from the evaporator to the condenser
5) Liquid layer distribution and in particular film thickness and shape of the liquid-vapor interface from the evaporator to the condenser using visual observation and quantitative analysis (*e.g.* interferometric techniques) during heat pipe operations, *i.e.* from relatively low power up to the dry-out limit for the different working fluids.
6) Flow visualization shall be considered also for liquid velocity measurements.

**Experiment concept diagram**

SELENE represents a model of heat pipe with capillary structure for the investigation of the heat transfer performances, *e.g.* thermal resistance and maximum heat flux from the evaporator to the condenser, as well as of the basic fluid dynamics and physicochemical mechanisms occurring in heat pipes when multi-component fluids with anomalous surface tension behavior are considered.

The facility will contain several model heat pipes partially filled with different fluids on ground after vacuum conditions. According to the available volume, therefore, an experiment container with a number of transparent model heat pipes shall be developed (Figure 1). The main idea is to enable independent and sequential and/or simultaneous investigations of the different fluid mixtures.

Each cell can be simply a rectangular half-heat pipe model with one groove of appropriate cross section shape and size machined onto a solid plate. The investigation of the behavior of the liquid in this groove, when the system is subjected to different heat stimuli, is the main objective of the experiments. For each heat pipe, evaporation will be promoted at the hot side (evaporator) with a controllable heater or with a number of heaters located at one bottom side of the groove, while the temperature at the other end (condenser) should be controlled, *e.g.* by a Peltier element or by water cooling system. For a given temperature difference, corresponding to a prescribed thermal power, the evaporated liquid will condense at the cold opposite side where heat will be removed by the cooling system and the condensate liquid will be driven back to the evaporator flowing along the channel by the capillary effect plus the inverse Marangoni effect.

The different model heat pipes will be filled with different liquids, binary or multi-component self-rewetting fluids. Each heat pipe will be evacuated and partially filled with liquid before launch.

A set of temperature and concentration sensors shall be mounted on each model heat pipe. In particular, microsensors for measurements of liquid refractive index

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should be considered in order to evaluate the liquid concentration once the temperature is known.

In addition, a CCD camera, an infrared camera and interferometric analysis will complete the investigation of the basic fluid physicochemical mechanisms occurring in the heat pipe model. Main objectives will be the quantitative investigation of the liquid-vapor interface shape, of the liquid volume and distribution, as well as of the liquid velocity field.

**Conclusions**

The scientific requirements of SELENE project will be defined through theoretical and numerical analyses, as well as ground-based experimental activities with the objective to identify the flight experimental liquids, the scientific requirements for the development of the flight hardware and the diagnostic systems. Different ground-based experiments have already been started: theoretical and numerical models of heat transfer mechanisms and liquid distribution are in progress in microgravity laboratory of Department of Space engineering (DIAS) of University of Naples. An experimental cell has been realized in AIST in order to study the best configuration of setup and in particular what could be the problems during the space mission in order to avoid these with different solutions.

Last but not least, a long collaboration between DIAS and Utsunomiya University on different class of nanofluids has been conducted not only for their enhanced thermal conductivity and better wettability but also for utilization of this kind of nanofluid as "natural" tracers for optical system for flow visualization.

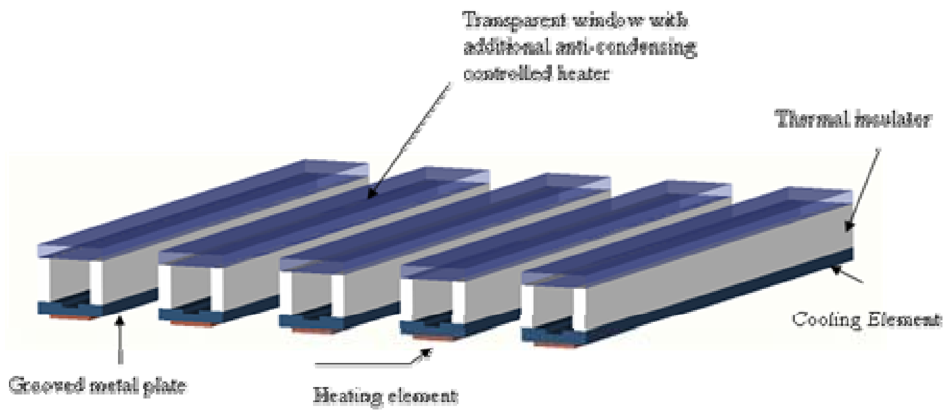


**Figure 1: Typical layout with 5 model heat pipe cells**

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