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The ESA Contribution to Space Research on Two-Phase Systems

This paper gives an overview of the research programme in Heat and Mass Transfer coordinated by the European Space Agency (ESA).
This research programme consists of six projects involving more than 30 partners, both academia and industry, spread in 11 countries in Europe, Canada and Israël.
The microgravity experiments performed up to now are recalled as well as their main results. Finally, the experiments planned for the coming years, particularly in the Fluid Science Laboratory (FSL) on the International Space Station (ISS), are briefly described.

Introduction

Fluid systems and fluid processes at all scales are omnipresent in everyday life. For example, energy generation relies on the phase change of a fluid to drive the turbines that produce electricity in the end. Systems relying on heat transfer range from electronics cooling to air conditioning units in cars or buildings. Water and food production processes also rely on multiphase systems: sugar, dairy products and fruit juices are produced at industrial scales by way of falling film evaporators.

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Space systems, satellites as well as manned spacecraft require efficient and reliable environment control, human life support and advanced power and propulsion systems. For example, telecommunication satellites are becoming increasingly packed with high-power electronics while being under severe weight reduction pressure.

All these very diverse applications have in common the same physical phenomena (evaporation, boiling, condensation). However, in the industrial world, empirical correlations are still widely used for systems design because the complexity of phenomena makes it very hard to develop accurate physical models. Developing such models requires a deeper understanding of the basic phenomena. The knowledge-based optimisation or design of systems with enhanced performance requires investigations on these physical phenomena in a multi-scale and multi-disciplinary approach.

The ESA projects

Studies in the space environment contribute tremendously to advances in this field. The results bring about quantitative knowledge that will support the development and validation of reliable prediction capabilities and respond to the pressing demand of industry.

Projects in the ELIPS (European Life and Physical Sciences in Space) research programme coordinated by ESA capitalise on prior investment and will deliver the much awaited data, with an ever-growing industrial support. This is made possible by an integrated approach in which the projects are incubated in ESA-sponsored Topical Teams (joint working groups between academia – theoreticians, code developers, experimentalists – and industries) before being implemented in flight opportunities (see Table 1).

These experiments make use of the full array of facilities available for microgravity research: drop tower, parabolic flights, sounding rockets (Maser, Texus), unmanned capsules (FOTON) as well as on the International Space Station (ISS).

Results already obtaind

Several experiments tackled the fundamentals of liquid layers. In BAMBI (Bifurcation Anomalies in Marangoni-Bernard Instabilities) on FOTON-M2, interferometry, infrared and velocimetry images were obtained on a layer of silicon oil heated from below, enabling the observation of convective patterns. In ITEL [1] (Interfacial Turbulence in Evaporating Layers), flown on sounding rockets twice, the use of a tomography based on 6 Mach-Zehnder interferometers allowed 3D reconstruction of the temperature field in an evaporating layer with gas circulation, while Schlieren observation showed instabilities (ripples) on the free surface.

Table 1: Summary of ESA projects in Heat and Mass Transfer

Project name	Past experiments	Future experiments
CIMEX: Convection and Interfacial Mass Exchange	PFCs* BAMBI DAGOBERT (FOTON M2, 2005) ITEL (Maser, 2002, 2005) HEAT (ISS, 2004)	TEPLO (FOTON M3, 2007) CIMEX, RUBI, EMERALD (FSL on ISS)
DOLFIN: Dynamics of liquid film/wall interactions	PFCs*	DOLFIN (Texus-45, 2007) SAFIR (FSL on ISS)
BOILING: Boiling, heat transfer and fluids management	PFCs* ARIEL (FOTON M2, 2005)	RUBI, DYAMOND (FSL on ISS)
CBC: Convective boiling and condensation	PFCs*	SOURCE on Maser-11 (2008) RUBI, DYAMOND (FSL on ISS)
ENCOM: Enhanced condensers for microgravity	PFCs*	CIMEX, SAFIR, EMERALD, DYAMOND (FSL on ISS)
MIX: Heat transfer devices with binary mixtures: integrated in other experiments.		

* PFCs = Parabolic Flight Campaigns

Other experiments concentrated on the fundamentals of boiling. ARIEL [2] (Analysis of heat transfer Regime Improved by Electrostatic fields in Liquids) showed quantitatively the influence of electric fields of various magnitudes on the detachment of vapour bubbles and consequently on the heat transfer. Single bubble experiments in parabolic flights demonstrated that most of the boiling heat transfer takes place in the so-called micro-region, at the triple junction between the hot surface, the liquid and the vapour.

Last but not least, these fundamental results were put into practice in experiments like HEAT (Heat transfer performances of a grooved heat pipe) and DAGOBERT (Design of an Advanced GrOoved Board EvapoRaTor), which proved the superior performance of evaporators with a higher groove density.

The results of most of these experiments are reported by the scientific teams in this workshop.

Parabolic flight campaigns

Extensive investigations are on-going in the following fields, with several partners participating on a regular basis in the ESA Parabolic Flight Campaigns:

- Flow boiling and quenching in tubes (∅ 2, 4 and 6 mm) [3];
- Flow boiling in mini-channels (254, 454, 654 µm thick) [4];
- Thin-film evaporator, condensation-separation system.

Future instruments

The TEPLO experiment on FOTON-M3 will be a continuation of HEAT as technological test of an enhanced heat pipe together with a loop heat pipe. Two sounding rocket experiments are foreseen: DOLFIN to investigate spray impact on a heated target (sponsored by DLR), and SOURCE to gather data of relevance to the behaviour of cryogenic fluids in a tank in microgravity (Marangoni convection, boiling, depressurization).

The CIMEX experiment onboard the ISS will capitalize on the successful experience of ITEL; the longer microgravity duration will allow to study different liquid layer compositions and depths, as well as gas compositions, flow rate and pressures. It will also provide local temperature measurements at the evaporating interface. This experiment is currently in the detailed design phase.

For boiling and condensation, four integrated experiments are foreseen:

- RUBI: Reference mUltiscale Boiling Investigation;
- SAFIR: Single fin condensAtion: Film local measurements;
- EMERALD: Enhanced Methods for hEat tRAnsfer in a Loop heat pipe Demonstration;
- DYAMOND: DYnamics and heAt transfer Mechanisms in flOw boiling and coNDensation.

The requirements for these experiments are under definition and feasibility studies will be started in the near future.

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More details on the past experiments can be found online in the ESA Erasmus Experiment Archive: http://eea.spaceflight.esa.int/