Heat transfer in pool boiling under microgravity

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INTRODUCTION

In the last few years we have carried out a whole series of pool boiling experiments under microgravity (μ-g) to study the influence of system acceleration on the boiling regime. The program started in the early 1980s with some basic experiments on the stability of the boiling process under reduced gravity. After this was achieved, especially for subcooled conditions, a series of parabolic flights was used to measure boiling curves for the fluid Freon 12.

EXPERIMENTAL DETAILS

During various flights several test fluids combined with several heaters were used to study the influence of the different system parameters:

Freon 113: platinum wire 9.2 mm in diameter; saturated ($T_{\rm sat}$ = 30°C; $p/p_{\rm crit}$ = 0.015) and subcooled ($T_{\rm sat}$ = 47°C; $p/p_{\rm crit}$ = 0.03; $T_{\rm sat} - T_\infty$ = 17 K) fluid state; see Weinzierl[1]; flat plate: saturated ($T_{\rm sat}$ = 30°C; $p/p_{\rm crit}$ = 0.015) and subcooled ($T_{\rm sat}$ = 47°C, 77°C; $p/p_{\rm crit}$ = 0.03, 0.06; $T_{\rm sat} - T_\infty$ = 17 K, 47 K) fluid state; see Zell.[2]

Freon 12: platinum wires 0.2 and 0.05 mm in diameter; cylinder 8 mm in diameter; flat plate; saturated ($10 < T_{\rm sat} < 90$°C; $0.11 < p/p_{\rm crit} < 0.68$) and subcooled ($10 < T_\infty < 90$°C; $p/p_{\rm crit} < 0.68$) fluid state; water; platinum wire 0.2 mm in diameter; subcooled liquid.

REDUCED GRAVITY CONDITIONS

Reduced gravity conditions may be achieved in two different ways. It is possible to compensate the gravity force by a second body force, e.g., the centrifugal force. This is done in Fig. 1, which shows an example of a boiling regime for reduced and for earth gravity at the saturated state. Dramatic changes take place during the switch to μ-g: the bubble population, consisting of many small bubbles, is replaced by a few big bubbles, but the heater temperature remains fairly unchanged. Consequently, the change in the heat-transfer coefficient is only very small.

This behavior applies, generally speaking, to most cases, regardless of the fluid type, the heater geometry, or the fluid state. Figure 2 may serve as one example: the system platinum wire–Freon 12 at saturated state for several pressure ratios $p/p_{\rm crit}$. Measurements at reduced gravity are denoted by symbols, and the reference measurements at the same heat-flux levels are denoted by lines. As is seen, the heater temperatures change only slightly. For low heat-flux levels, the heater temperatures are even smaller for the μ-g system, but higher for higher heat fluxes. This behavior is reinforced for larger $p/p_{\rm crit}$ ratios. This can also be seen in Fig. 3. The ratio of the heat-transfer coefficients is approximately 1 for all heat-flux levels (case p_r = 0.68 excluded). As a consequence, we must say that heat transfer cannot be a significant function of the bubble departure diameter, which changes drastically, as can be seen in Fig. 1.

Basically this is also true for pool boiling in subcooled liquids. Results for constant bulk liquid temperature and different system pressures show the advantages of the μ-g system for low heat fluxes, whereas higher heat fluxes lead also to higher heater temperatures.

But what is the reason for that? Under earth conditions buoyancy forces influence the flow field around the heated wire, especially at the bottom of it. Bubbles will accumulate at the top of the wire. On the other hand, in a weightless environment, boiling takes place symmetrically around the wire, helping to keep the heater temperatures low. Therefore, the resulting values for α will be higher, compared to earth conditions.

CONCLUSIONS

Pool boiling under microgravity is certainly possible. Moreover, the heat-transfer coefficients remain nearly constant. In some cases even higher values for α could be found. This system's behavior is not influenced very much by the thermodynamic properties or the heater geometry. For technical applications of saturated boiling, flow convection should be used to move the vapor volumes away from the heating surface. Subcooled boiling would not require such a device and provides the best conditions for safe application.

Shuttle Flights in Orbits 320 km above Ground. The second possibility is to perform free-falling experiments. Inside a test vessel everything is falling with exactly the same speed, so the components do not interact any more. The two facilities presented below belong to this category.

FIG. 1. Boiling regime for μ-g and earth gravity.

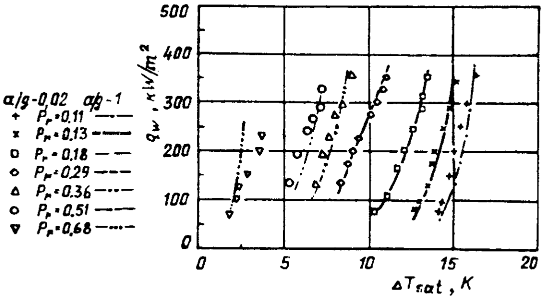

FIG. 2. Boiling curves for platinum wire 0.2 mm in diameter in Freon 12 at saturated state.

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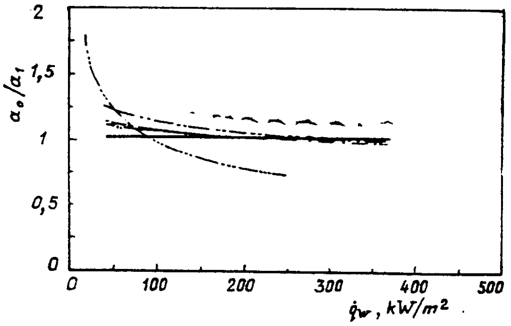

FIG. 3. Heat-transfer coefficient as a function of the pressure ratio p/p_{crit} at different p_r: 0.11 (–), 0.13 (–), 0.18 (– – –), 10.29 (–~–), 0.36 (–····–), 0.51 (–~~~–), and 0.68 (–ʌʌ–).

TEXUS BALLISTIC ROCKET

TEXUS [Technologische Experimente unter Schwerelosigkreit (gravity-free technical experiments)] is a German space research program sponsored by the BMFT and managed by the DLR (DFVLR). The small rockets (450 mm in diameter), capable of carrying up to a 400-kg payload, are launched near Kiruna, Sweden. The experiments with a typical weight of 60 kg work automatically, data recording being done by a telemetry system capable of a maximum measuring speed of 100 Hz per channel. The acceleration level is better than 10^{-4} g (ensuring that g = 9.81 m/s^2), and the μ-g period lasts up to 6 min. Due to weight considerations, we used Freon 113 in this facility (no pressure vessel required at room temperatures).

KC 135 PLANE

Another part of the German microgravity program uses an airplane from NASA/Houston, similar to a Boeing 707, to carry out parabolic flight. The duration of reduced gravity periods is 15–20 sec per parabola, and the gravity level changes from 2g to ±0.02g. During one flight, up to 30–40 parabolas may be reached, so that an experimental time of approximately 500 s is available. In this facility, laboratory hardware can be employed, and the experiments are controlled by the principal investigator himself, which is unique for microgravity experimenting. Here we ran all the Freon 12 measurements, but also some additional ones with Freon 113 and water.

RESULTS WITH THE FLUID FREON 12

As mentioned earlier, measurements within a wide range of the thermodynamic variables T, p were made. At each point several heat-flux steps can be combined to a boiling curve for reduced gravity, earth gravity, and elevated gravity. Due to the flight profile, measurements for the several acceleration levels followed one another consecutively, rendering possible a direct comparison of the heater temperatures. The platinum wires, having small heat capacities, form a measuring instrument that is capable of reacting very rapidly and that is sensitive to changes in heat transfer, thus excluding delayed experimental responses.

[1] A. Weinzierl, "Untersuchung des Wärmeübergangs und seiner Transportmechanismen bei Siedevorgängen unter Mikrograv itation," Dissertation an der Technishen Universität, München (1984).

[2] M. Zell and J. Straub, "Microgravity pool boiling — TEXUS and parabolic flight experiments," in: Proc. 6th European Symposium on Material Sciences under Microgravity Conditions (1986).