Group: Multi Phase Flow

Detailed investigations on flow boiling of water up to the criticalheat flux

Stephan Gabriel, Giancarlo Albrecht

Introduction

Multiphase flows occur in various fields of process engineering and energy technologies. Highly complex phenomena such as flow boiling up to the critical heat flux (CHF) or counter current flow limitation CCFL arise from a whole series of phenomena such as convection, bubble formation, evaporation, condensation, drop/bubble fragmentation or coalescence and many more. In order to to understand the behaviour of two-phase flows in real technical systems in detail, it is necessary to consider both the individual phenomena and the more complex phenomena in the experiment and to advance the development of simulation programs with detailed data sets.

The Group Multiphase Flows (MPF) works therefore on investigations at different scales from experiments on single effects [4] to experiments on complex phenomena like CHF. Since the required measurement technology is in many cases not commercially available, the development of suitable sensors, for example for the acquisition of detailed phase distributions, is also part of the task.

Results

In 2019, the focus of work was on the construction of the high-pressure test facility COSMOS-H on the one hand, and on the other the completion of measurements on a rod bundle test section of the low-pressure test facility COSMOS-L. As a further important work package, extensive work was carried out on modernizing and upgrading the laboratory infrastructure in view of the upcoming commissioning of COSMOS-H. This includes the procurement or recommissioning of laboratory equipment such as tensiometers, microscopy and measuring instruments for determining water quality for the tests and as a precondition for the tests the upgrading of the crane technology for the new test track. In addition, the dismantling of the meanwhile 20-year-old test facility DISCO was carried out to create urgently needed space for COSMOS-H.

<u>COSMOS-L</u>

At the COSMOS-L test facility in 2019, further measurements were made to complete a dataset on a rod bundle and then a new test track with a flat vertical heater was developed. A measurement data set for the rod bundle consisting of 5 Zircalloy tubes, which was created within the framework of the joint project NUBEKS [2,3], was supplemented by further measurement points and measured variables. The measurements characterize the behaviour starting from flow boiling up to the boiling crisis (CHF). As can be seen in Figure 1, the test section has a rod bundle consisting of five separately heatable cladding tubes. During the tests, either all tubes were heated in order to obtain the most realistic phase distribution around the central tube, or only the central tube was heated in order to concentrate the instrumentation there. The results presented below were obtained by experiments with only one heated tube.

The test results presented in the following refer to a static pressure of 1200 mbar, a mass flow density of 50 kg/(m²s) and a test track inlet temperature of 80°C. This corresponds to an inlet subcooling of approx. 25°C. As shown in Figure 2, bubble boiling already occurs at a heating power of 4 kW, which becomes more and more intensive with increasing heat flux. The critical heat flux is reached at this boundary conditions at a heating power of approximately 10.8 kW.

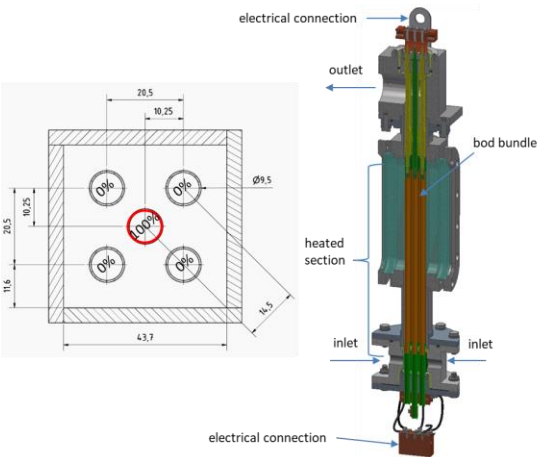

Figure 1: Experimental setup of the bundle measurements

Analogous to the previous experiments 2018, the experiments were repeated several times, here a total of 29 times, and a frequency distribution of the CHF value was generated (see Figure 3). The measured values related to the heated surface thus result in a critical power of CHF_{mean} =1.1257 MW/m² with a standard deviation of σ =0.013 MW/m².

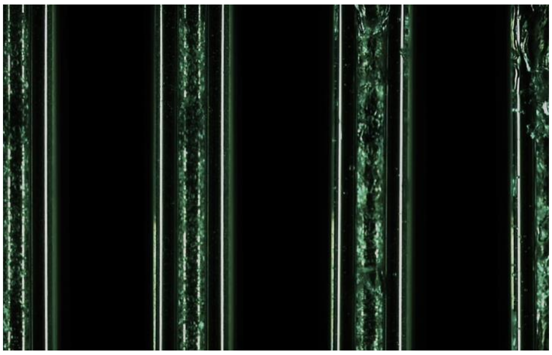

Figure 2: Flow pattern as a function of heat output

In addition, the locations where the CHF occurred on the cladding tube could be calculated by correlation of the three thermocouples closest to the hotspot [5]. For this purpose, the heated pipe in the test section is divided into triangles between each three thermocouples. The measured temperature values show different signals depending on how close they are to the location of the CHF. Characteristic here are on the one hand the waiting time, i.e. the running time of the signal, and on the other hand also the temperature gradient.

After the basic function of the principle was demonstrated on a sheet metal of 40 × 40 cm² with a propane gas burner as heat source, the CHF events of the COSMOS-L measurements were evaluated concerning the frequency distribution shown above. It is evident that the

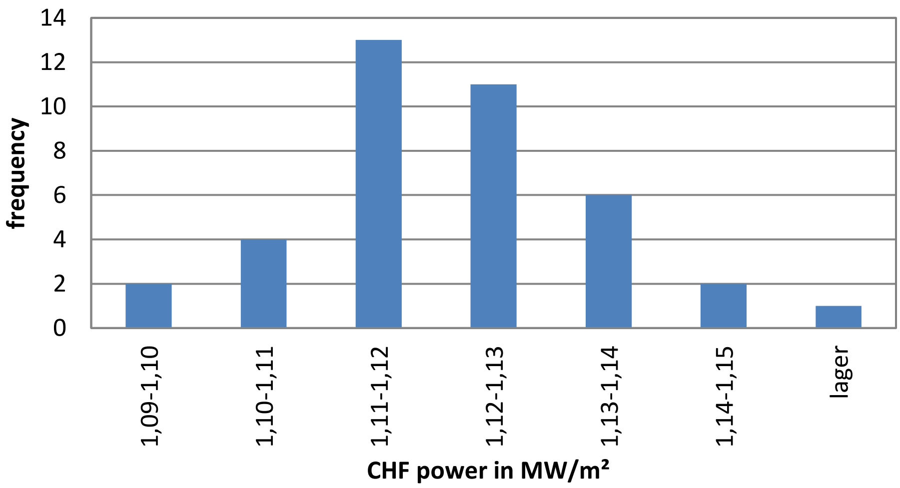

Figure 3: Frequency distribution of the critical heat flux after 29 tests

method has room for improvement in terms of precision. However, it can certainly be used to determine during a test whether the CHF events always occur at the same location, which would be an indication of damage to the heating tube.

As expected, most CHF events could be identified at the upper end of the 326 mm long heated tube. It was found that although there are accumulations of CHF events but they rarely occur directly one after the other [5].

Following the rod bundle experiments, the design and construction of a new test arrangement for experiments within the project KEK-SIMA was started, in which, together with the Institute of Applied Thermofluidics (IATF), the effects of transient mass flows on the critical heat flow density will be investigated. For this purpose, a test section with a plate-shaped heating element was constructed in 2019 (see Figure 5). In addition to a powerful heater, the test section also has three window elements for observing the flow and numerous sensors for recording all relevant boundary conditions. A precondition for the upcoming tests is an increase in performance and an extension of COSMOS-L by numerous pressure, temperature and mass flow sensors. In addition, a bypass to the test track will be installed in the coming year in order to ensure stable system operation and thus reproducible test boundary conditions even with fluctuating mass flows in the test track.

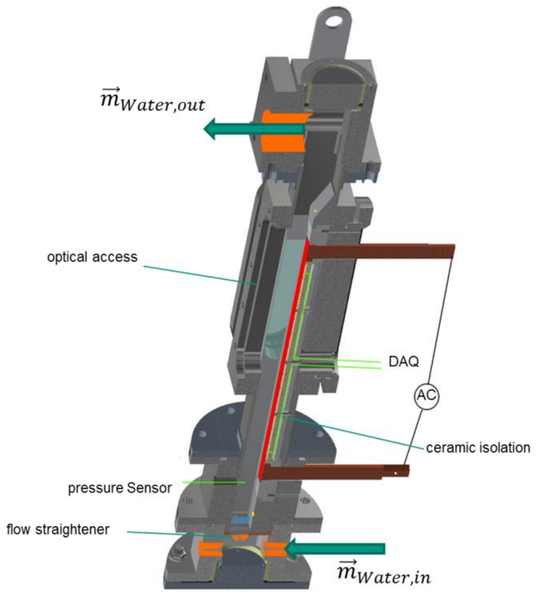

Figure 5: New test section concept with flat heater to investigate the critical heat flow density with flucuating mass flows

COSMOS-H

The thermohydraulic test facility COSMOS-H is a high pressure high temperature water loop being built for the investigation of boiling phenomena and other flow phenomena that can occur in thermal power plants. In contrast to COSMOS-L, the loop will achieve non-scaled test conditions comparable to a boiling water

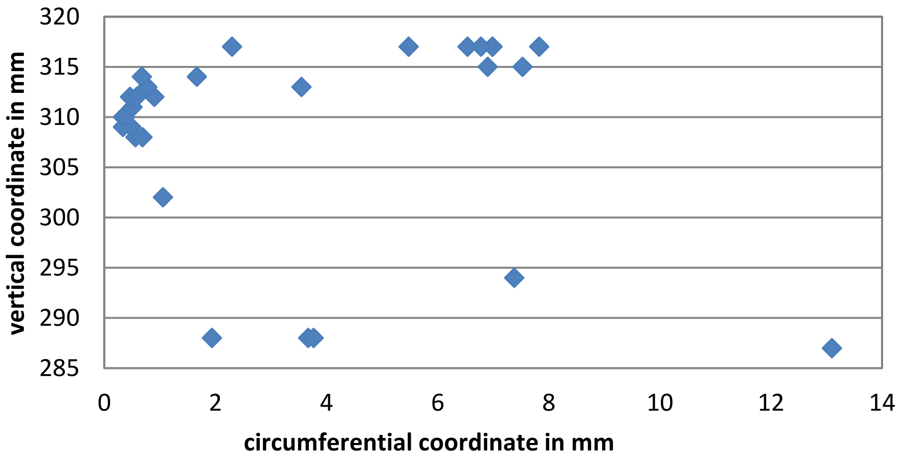

Figure 4: Local distribution of CHF events on the middle pipe [5].

reactor or pressurized water reactor (up to 170 bar, 360°C) during test operation. The work on the construction of the COSMOS-H test facility was continued as planned in 2019. Numerous subsystems were completed and some have already been commissioned (see Figure 6). These include, for example:

- The power supply for the control system and all electrical consumers was completed
- The two cooling loops of the facility were completed (cooling capacity 1.8 MW)
- The compressed air supply to drive the automatic valves is completed, including the emergency supply system.
- The hardware of the digital control system (SPS) as well as the technology of the control station is completed.
- The pumps and valves of the plant are now functional.
- The crane technology for the assembly and installation of the test track, consisting of assembly crane, transport trolley, crane traverse and hall crane, has been completed.

Further work is now concentrating on completing the high-pressure loop and the necessary safety systems.

Acknowledgement

We thank Mr. Wilson Heiler, ProScience, for his valuable contribution to our experiments. We would also like to thank Prof. Thomas Wetzel and Dr. Philipp Dietrich for their excellent cooperation in the joint project NUBEKS. Furthermore, we would like to thank Prof. Xu Cheng and Stelios Michaelides (IATF) for their good cooperation in the SIMA project.

Figure 6: Images of various subsystems of the plant under construction

References

[1] Tromm, Th. W.; Kaiser, F.; Gabriel, S.; Heiler, W.; Albrecht, G.; “Investigations on Flow Boiling under forced Convection on Zircaloy Tubes up to Critical Heat Flux” (NENE2019) 9-12.9.19 Portoroz Slovenia

[2] Kaiser, F.; Dietrich, B.; Gabriel, S.; Wetzel, T.; „Final Report Project NUBEKS Experimentelle Ermittlung von kritischen Wärmestromdichten bei reaktortypischen Bedingungen als Validierungsdaten“ 27.02.2019 (BMWi 1501473B)

[3] Lifante, C.; Ben Hadj Ali, A.; Eickenbusch, H.; Bruder, M.; Kaiser, F.; Gabriel, S.; “PREDICTION OF CONVECTIVE BOILING UP TO CRITICAL HEAT FLUX (CHF) CONDITIONS FOR TEST FACILITIES WITH VERTICAL HEATERS”, 27th International Conference on Nuclear Engineering, May 19-24, 2019, Ibaraki, Japan

[4] Albrecht, G.; Heiler, W.; Büttner, F.; Gabriel, S.; “Experimental investigation of air entrainment by a vertical jet plunging into a liquid

pool”, 10th International Conference on Multiphase Flow, ICMF 2019, Rio de Janeiro, Brazil, May 19 – 24, 2019

[5] Bernez, V.; “Measurement of bubbles dynamics in a five-strand bundle”, MASTER THESIS, KIT, 2019