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Thermal−Hydraulic Test Facilities and Some Test Results of Integrated Heating Reactors

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Abstract

Since the middle of the eighties of this century a research program both for heating reactor and investigation of heating reactor thermal−hydraulics has been carried out in Institute of Nuclear Energy Technology(INET) of Tsinghua university in China. This kind of heating reactor is a light water cooled and integrated natural circulation reactor with low system pressure and low quality at the exit of core. Because of relatively long riser and low system pressure, a little change of the quality at the exit of the core will result in a relatively large variation of void fraction in the riser. Two full scale test loops, HRTL−5 and HRTL−200 simulating the HR−5 and HR−200 heating reactors in geometry and operation parameters respectively, and some test results from the HRTL−200 test facility are shown in this paper. The range of studied system pressure is from 1.0MPa to 4.0MPa, the largest heat flux is about 50 W/cm2, and the quality at the exit of test section is less than 5%.

Ⅰ. Introduction

A slightly boiling integrated−type reactor whose schematic diagram is shown in Fig. 1 is expected to be one of advanced designs for heating reactor. A testing 5MW heating reactor, one of above type of heating reactor, had been built in INET in 1990 and has been operated successfully up to date, another commercial heating reactor, HR−200[1], with the same design idea as this testing 5MW heating reactor will be built in northeast China in the near future.

In order to enhance natural circulation ability in this heating reactor the coolant water is heated to the condition of slightly boiling in the core, and there is also a relatively long riser above the core. Because the coolant

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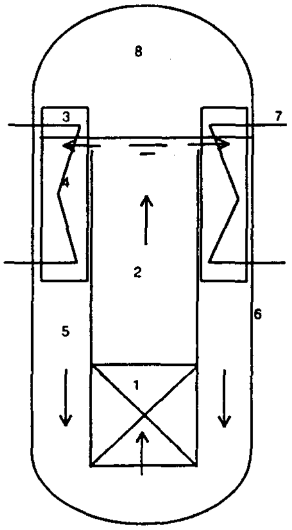
water circulates naturally in the reactor with relatively low system pressure P (less than 2.5MPa), and low quality X_e at the exit of the core(less than 1%), a small perturbation of the quality at the exit of the reactor core will result in a relatively large change of the void fraction in the riser, so do the natural circulation driving force and the mass flow rate.



1-Core 2-Riser
3-Condensor 4-Heat exchanger
5-Downcomer 6-Vessel
7-Second loop 8-Pressurizer

Fig. 1 Schematic diagram of 200MW heating reactor

As be well known, in systems and components with two-phase flow such as boiler, steam generator, nuclear reactor, and some chemical facilities two phase flow instability may be initiated under certain operation conditions[2]. The flow instability may cause many problems such as mechanical vibration, crisis of local heat transfer, and void reactivity feedback special for nuclear reactor. Although the nuclear-coupled two phase flow instability is not important in modern BWRs which are operated under relatively high system pressures, the effect of flow instability should be paid enough attention in this kind of heating reactor because the system pressure is much lower than one in modern BWRs. In order to accumulate experimental data for verification of the models and codes used in design and safety analysis of this new kind of heating reactor, two full scale test loops, HRTL-5 and HRTL-200 simulating the HR-5 and HR-200 heating reactor in geometry and operation parameters respectively, have been constructed in INET and a series of experimental investigation[3,4] has been carried out for over ten years. The introduction on these two test facilities and some test results from the HRTL-200 test facility are shown in this paper.

II. Heating Reactor and Their Test Facilities

5MW testing heating reactor is the first kind of heating reactor operated in the world, its design system pressure is 1.5MPa, and the heating power is 5MW. As the first step of the development it is now operated under the condition of pressurized water. The experimental work about generating electricity and desalinating sea water also has been finished successfully in this reactor.

Fig. 2 shows the schematic diagram of the simulating test loop of the 5MW heating reactor. There are two parallel electric heated test sections and two risers, every heating rod bundle is composed of 16 rods, the total maximum heating power is about 360KW. The length of heating section is about 0.6 m, and the length of the riser is about 2.8m. The maximum operation system pressure is 2.0MPa.

200MW heating reactor will be the first commercial operation heating reactor in China, and maybe in the world. It is also a natural circulation, integrated–type, and passive heat–removal nuclear reactor. The design system pressure is 2.5MPa, and the heating power is 200MW. The heated length of the fuel rods is 1.9m, and the length of riser is 5.0m.

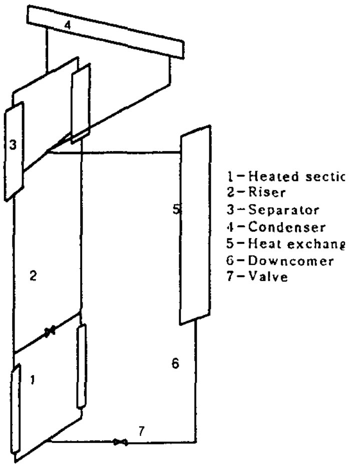


Fig. 2 HRTL–5 test facility

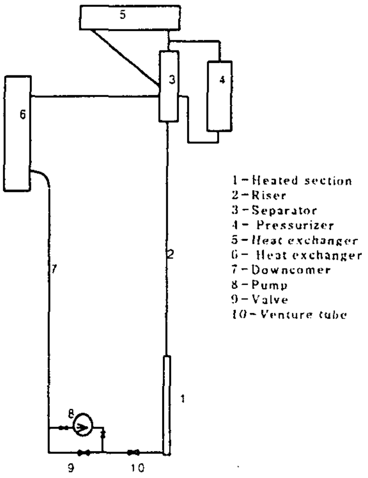


Fig. 3 HRTL–200 test facility

The schematic diagram of primary loop of the HRLT–200 test system is shown in Fig. 3. The total test system consists of primary loop, secondary loop, ancillary cooling loop, electrically heating system and measuring system. The primary loop is composed of electrically heated test section, riser, steam separator, steam condenser, heat exchanger, pressurizer, downcomer, valves, pump and connection tubes. The test system can be operated in natural or forced circulation mode. The vertical test section consists of 9 electrically heated rods with uniform power distribution, the stone insulation layer and pressure vessel. The heated rods are made of stainless tubes with 10.0mm OD, and arranged in 3×3 cluster with a pitch of 13.3 mm. The heated section and the riser have the same length as ones in the prototype reactor. The following are the main design parameters: the maximum system pressure 4.0MPa, the maximum heating power 400KW, the maximum temperature over 250℃, the range of inlet subcooling 5~80℃, the range of inlet resistance coefficient 10~200.

Same as in heating reactor, desalinated water is used as working fluid. The coolant water enters the heated section with the required subcooling and is heated to the slightly boiling condition in the heated section, then the two phase mixture flows upright through the riser into the steam separator, the separated steam is condensed in the condenser and then mixes with separated water, passing through the heat exchanger and downcomer, at last, reenters the heated section.

The mass flow rate G, system pressure, inlet and outlet temperature T_{in}, T_{out} of the heated section, heating power W, and many other parameters are measured and recorded during experiments. The steam quality is calculated from the heat equilibrium, and the void fraction is obtained from the measurement result of pressure difference.

Ⅲ. Test Results

During experiments four parameters can be adjusted, they are system pressure, heated section inlet subcooling $\triangle T_{sub}$, inlet resistance coefficient K_{in}, and heating power. Keeping P, K_{in}, and W constant, when $\triangle T_{sub}$ is adjusted from large value to small value the flow instability is initiated in a range of medium subcooling(see Fig. 4, $\triangle G$ and G are peak to peak value and averaged value of mass flow rate respectively). The unstable region is defined as $\triangle G / G$ greater than 5%.

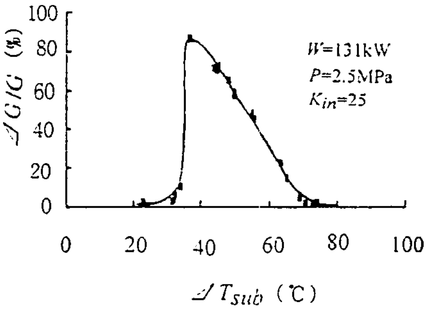


Fig. 4 Flow rate relative amplitude versus inlet subcooling

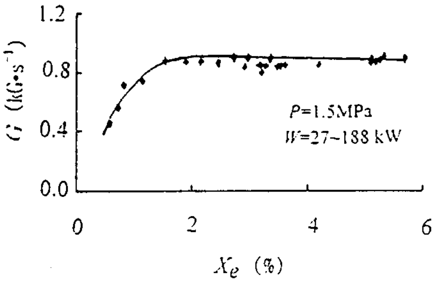


Fig. 5 Mass flow rate versus quality

Keeping P, K_{in}, and $\triangle T_{sub}$ constant, the mass flow rate G of the natural circulation will increase with increasing heating power, but the increase of flow rate is not linear. An increasing in inlet subcooling results in loop mass flow rate decrease, but the decrease speed becomes smaller at higher power. An increase in system pressure also results in a loop mass flow rate decrease. Fig. 5 shows that if we put quality X_e as the horizontal coordinate all of the different heating power and subcooling test data points lie almost on a same curve. The trend void fraction versus quality is similar to that of mass flow rate versus quality. This certifies that the buoyancy driving force is dominant under low quality region.

An increase in heating power will result in large unstable region and small oscillation period, but the maximum relative oscillation amplitude of mass flow rate almost does not change.

An increase in system pressure will result in decrease of maximum relative amplitude of mass flow rate(see Fig. 6), but the oscillation period almost dose not change(see Fig. 7). At low pressure an increase in system pressure makes the unstable region decrease relatively fast, while over about 3.0MPa the unstable region almost does not decrease with increasing system pressure(see Fig. 8).

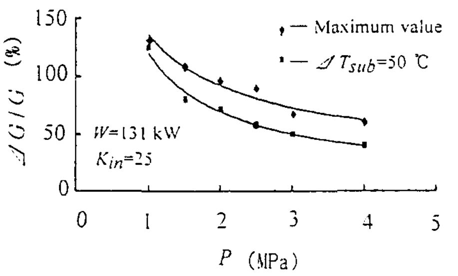


Fig. 6 Effect of system pressure on relative amplitude

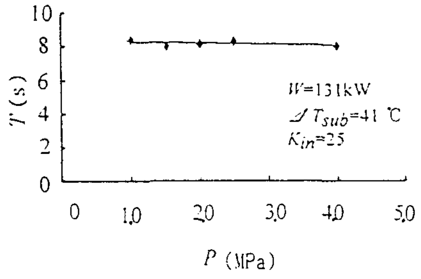


Fig. 7 Oscillation period of mass flow rate versus pressure

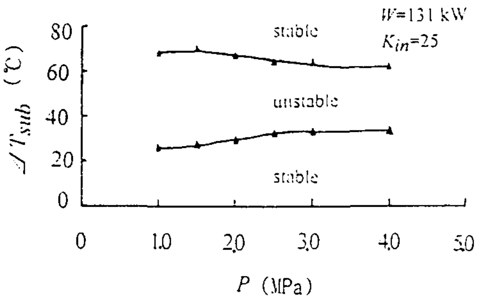


Fig. 8 Effect of system pressure on stable boundary

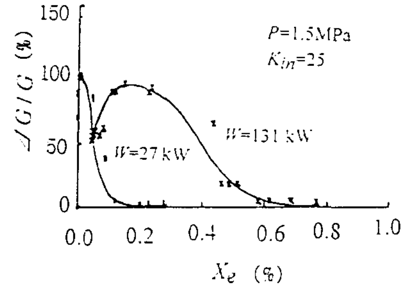


Fig. 9 Relative amplitude of mass flow rate versus quality

Keeping P and K_{in} constant, under different heating powers dependency of relative mass flow rate amplitude on X_e at the exit of heated section is shown in Fig. 9. This figure shows that all unstable points lie in the low quality region where X_e is less than 1%. It reveals that unlike in high quality unstable region this unstable flow region is in small quality region and the buoyancy driving force, not two phase flow frictional resistance, becomes dominant both for mass flow rate and for unstable flow region.ig. 10 shows the stability boundary map for this natural circulation loop with the same system pressure as one for the prototype 200MW heating reactor.

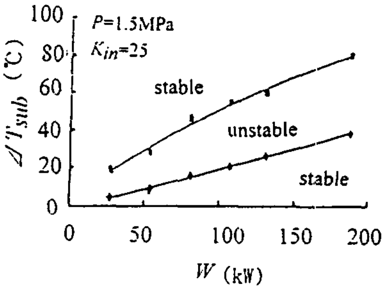


Fig. 10 Stability boundary map

Ⅳ. Conclusion

A series of experimental investigation for two phase flow instability in a natural circulation loop with low steam quality and low system pressure has been carried out in a broad range of test parameters covering the design pressure, temperature, and heat flux of 200MW heating reactor. The experimental results show that differing from the well known unstable region of density wave oscillations at high quality there is also an unstable region at low quality, in this region the quality, that is to say, the buoyancy driving force , rather than the two phase flow friction resistance is dominant.

Ⅴ. Acknowledgments

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Ⅵ. References

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