Nuclear Engineering and Technology 50 (2018) 1079–1087

Contents lists available at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Research on flow characteristics in supercritical water natural circulation: Influence of heating power distribution

Dongliang Ma [a, b, c, *], Tao Zhou [a, b, c, **], Xiang Feng [a, b, c], Yanping Huang [d]

[a] School of Nuclear Science and Engineering, North China Electric Power University, Beijing 102026, China
[b] Institute of Nuclear Thermal-hydraulic Safety and Standardization, North China Electric Power University, Beijing 102206, China
[c] Beijing Key Laboratory of Passive Safety Technology for Nuclear Energy, North China Electric Power University, Beijing 102206, China
[d] Science and Technology on Reactor System Design Technology Laboratory, Nuclear Power Institute of China, Chengdu 610041, China

ARTICLE INFO

Article history:
Received 20 March 2018
Received in revised form
11 June 2018
Accepted 11 July 2018
Available online 17 July 2018

Keywords:
Supercritical water
Power distribution
Natural circulation
Thermal resistance
Passive residual heat removal system

ABSTRACT

There are many parameters that affect the natural circulation flow, such as height difference, heating power size, pipe diameter, system pressure and inlet temperature and so on. In general analysis the heating power is often regarded as a uniform distribution. The ANSYS-CFX numerical analysis software was used to analyze the flow heat transfer of supercritical water under different heating power distribution conditions. The distribution types of uniform, power increasing, power decreasing and sine function are investigated. Through the analysis, it can be concluded that different power distribution has a great influence on the flow of natural circulation if the total power of heating is constant. It was found that the peak flow of supercritical water natural circulation is maximal when the distribution of heating power is monotonically decreasing, minimal when it is monotonically increasing, and moderate at uniform or the sine type of heating. The simulation results further reveal the supercritical water under different heat transfer conditions on its flow characteristics. It can provide certain theory reference and system design for passive residual heat removal system about supercritical water.

1. Introduction

The supercritical water reactor (SCWR) is the only water cooled reactor in the fourth-generation advanced reactor. It is characterized by high thermal efficiency and good economy. Usually in the event of an accident, the supercritical water reactor generates a huge waste heat. How the waste heat removed from the core of the reactor is closely related to the safety and stability of the reactor. The natural circulation flow can continuously export the residual heat in the core, which is a safe and reliable heat removal method. There are many parameters that affect the natural circulation flow, such as height difference, heating power value, pipe diameter, pressure, inlet temperature, and so on. *V. Chatoorgoon* et al. [1] calculated the influence of these major influencing parameters on the boundary conditions of the stability of supercritical water's natural circulation flow. But the calculation assumption is that the heating power is a uniform distribution. In the previous study and analysis, the power distribution in the core is also assumed uniform. But in the actual case, the heat release distribution in the core is usually not uniform. In the uneven heating core channel, the heat transfer characteristic has a large influence on the flow characteristics in the channel. *Zhang* et al. [2] conducted experimental studies on the stability of natural circulation under different power density distributions. The axial power distribution of a nuclear reactor, is generally affected by Ref. [3] the heat flux level, fuel consumption level, transient xenon distribution, control rod elevation and insertion level and so on. In the design of nuclear power plant, the heat flux distribution of the reactor is controlled by the normal axial migration control method. *Li* et al. [4] carried out a systematic experimental study on the inhomogeneous heat transfer of supercritical water in an inclined smooth tube. The study shows that it is prone to produce a stratification phenomenon at large heat flux. *Lei* et al. [5] numerically studied the non-uniform heat transfer characteristics of supercritical water in an inclined riser. *Lu xiaodong* et al. [6] calculated the influence of axial power distribution on the instability of supercritical water flow in parallel channels. In his paper, the concept of single-phase pressure drop

* Corresponding author. School of Nuclear Science and Engineering, North China Electric Power University, Beijing 102026, China.
** Corresponding author. School of Nuclear Science and Engineering, North China Electric Power University, Beijing 102206, China.
E-mail addresses: madongliang168@163.com (D. Ma), zhoutao@ncepu.edu.cn (T. Zhou).

https://doi.org/10.1016/j.net.2018.07.004

ratio is proposed to analyze the influence mechanism of axial power distribution on the stability of supercritical water in parallel channel systems. *Jia* et al. [7] proposed a new method for reconstructing the radial power distribution in the core by introducing the component cross section deviation. This method can be easily used to reconstruct the variation of power distribution caused by xenon gas fluctuation and moderator temperature field changes. *Cao* et al. [8] developed the fine power distribution calculation program for the core components of the sodium-cooled fast reactor. *Sheng* et al. [9] found that the occurrence of critical heat flux (CHF) in a natural circulation system has nonlinear chaotic characteristics. *Rowinski* et al. [10] carried out numerical studies on supercritical water flow under axial non-uniform heat flux. The research shows that the wall temperature distribution is highly dependent on the heat flux distribution form. If the peak point of wall temperature appears before the occurrence of heat transfer deterioration, it can reach a lower temperature distribution level compared with the uniform heat flux distribution form. *Paul* et al. [11,12] studied the nonlinear density wave instability under axial non-uniform heating condition. The results show that the linear stability of axial non-uniform heating is better than that of uniform heating. The single humped axial heat flux profiles are more linearly stable than dual humped profiles. The flow stability of the system varies greatly under different heat flux distribution conditions. *Rowinski* et al. [13] simulated the surface temperature distribution of supercritical water under the condition of uneven heat flux in 2 × 2 rod channels. The study shows that the distribution of heat flux has great influence on the distribution of wall temperature. Aimed at studying the influence of heat flow distribution on nucleate boiling point (ONB), the related experiment was carried out by *Al-Yahia* et al. [14]. At the non-uniform heat flow heating surface, the power value of the ONB point is about 25% lower than that when the surface is uniformly heated. *Habib* et al. [15] summarized the related experimental study and the progress of CFD in two phase flow when the radial and axial non-uniform heating were used to predict the CHF. *Lucas D* et al. [16] proposed a multiphase flow quality control strategy method for simulation analysis to facilitate the safety of nuclear reactions. *Liao Y* et al. [17] simulated the phenomenon of flash evaporation at different pressures. *Tang J* et al. [18] proposed a new method for steady state and transient nonlinear radial conduction problems in nuclear fuel rods. *Huang M* et al. [19] proposed a new method that can be used to solve complex geometry and multidimensional heat transfer flow problems. In case of supercritical water, the related research on the influence of heat flux distribution on the characteristics of flow is relatively less. Therefore, in the present work a numerical simulation method is used to analyze the distribution of several typical heat fluxes. The flow characteristics under different heating power conditions are investigated. The results can provide a reference for the design of in passive residual heat removal system for supercritical water reactor.

2. Simulation setup

2.1. Computational domain and mesh

The natural circulation loop of the single-channel supercritical water is studied. The natural circulation loop consists of preheating segment, experimental entrance section, test section, experimental exit section, cooling section and descent section. The main components of the simulation loop model are shown in Fig. 1.

In the process of simulation modeling, the test section is divided into 20 units of equal length. By setting the heating power value separately in each unit, the boundary condition setting can be carried out in different forms of power distribution in the whole test segment. Compared with the uniform distribution heat flux, the heat flux of the test section is set to the situation of power increasing, power decreasing and power sine distribution

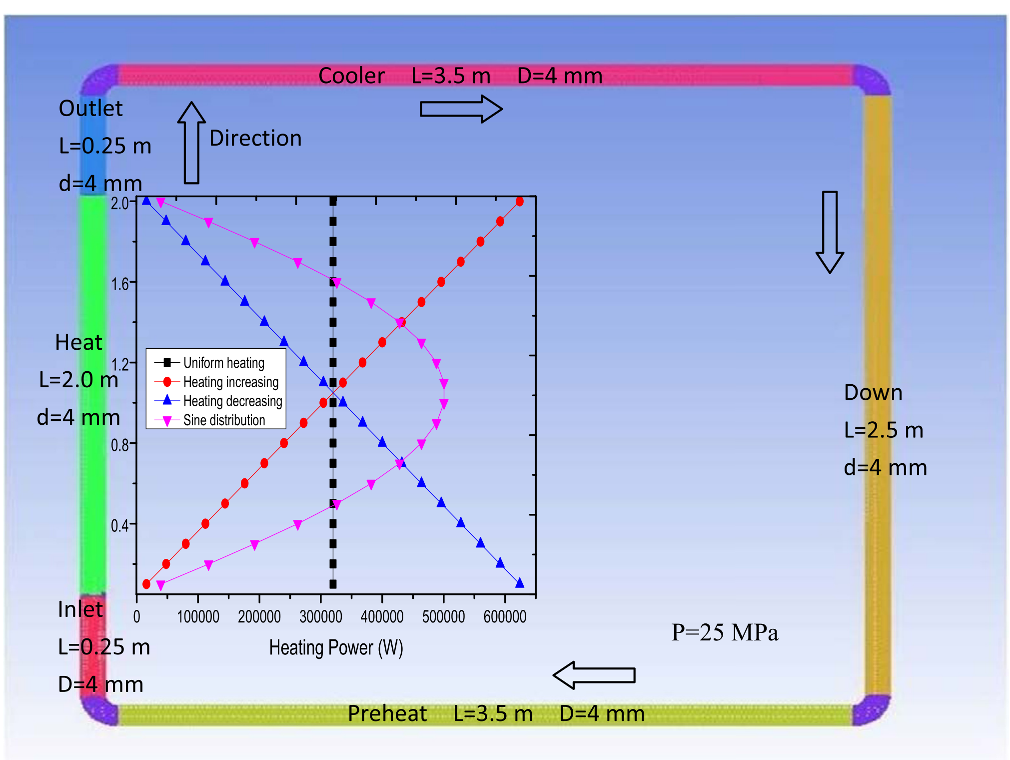

Fig. 1. Simulation model of supercritical water natural circulation loop.