Study on Numerical Calculation of the Shell Side Flow Field of the Space Spiral Section in Intermediate Heat Exchanger in China Experimental Fast Reactor

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Abstract. In the study of flow-induced vibration of nuclear grade heat exchanger, the distribution law of the flow field should be analyzed firstly. Taking the Intermediate Heat Exchanger (IHX) in China Experimental Fast Reactor (CEFR) as the research object, the computational fluid dynamics (CFD) method is used to establish the numerical calculation model of the shell side flow field of the elbow section of the heat exchanger in this paper. Method of the flow field distribution of the bend pipes is studied and analyzed, and the distribution characteristics of the flow field in the elbow section under different inlet velocity are analyzed. The results show that the flow angle and transverse flow velocity at the inlet of the elbow section are all larger. In the design, operation and maintenance of the heat exchanger, we should pay attention to the entrance of the elbow section.

1. Introduction

IHX is one of the most important equipment in a sodium cooled pool type fast reactor, which transports the heat from the primary sodium to the secondary sodium. Security and reliability is the most important request for development and design of nuclear grade heater exchanger, though greater demands were made for IHX [1]. Flow-induced vibration is one of the most important factors which results in damage to the tubes of IHX [2].

IHX is a vertical shell and tube type heat exchanger with primary sodium on shell side and secondary sodium on tube side. The middle part of IHX tube is a space spiral structure. The tubes of IHX are arranged in circular con-centric rows around a central down comer and the support structure of the tubes is quite special compared with other common heat exchangers [3].

The structure of IHX is special without codes and standards. So, 3D model of elbow section was build and the flow fluid distribution characteristics was researched in this paper by CFD. The distribution law of the flow field, impact of different inlet velocities on fluid distribution, fluid angle and velocity were researched by analysis of fluid distribution and fluid force change providing foundation data for flow-induced vibration of IHX.
2. Model and calculation assumptions

2.1. Model
The 3D model of elbow section was shown in Fig.1. The circumferential distribution of the heat exchanger tubes was periodic at fixed angle. Considering the uniformity of fluid distribution and reducing calculated amount, only one cycle was calculated in this paper. Except the elbow section, partial straight pipe section was saved in this model in order to stabilize the flow field. The flow direction was from top to bottom and the boundary conditions of the side walls shown in Fig.1 were periodic. The tube surfaces and the drum surfaces were setted wall boundary condition.

2.2. Assumptions and monitor points
On account of the complexity of structure and flow field, the mesh quantity may be too large to calculate if considering all details. It is necessary to simplify the models. The following simplified methods were applied according to basic assumptions used in computational fluid dynamics.

(1). The fluid was treated as incompressible;
(2). Ignore the vibration control belt which impact the shell flow field little;
(3). The heat exchange tubes were assumed as rigid as a foundation for further fluid-solid coupling analysis;
(4). The axial flow was main in the inlet of elbow section based on former results and changed little, so the velocity of inlet was regarded as constant and axial.

Three boundary conditions of inlet were applied to research the flow field characters. In case 1, the parameters of inlet and outlet were from calculation on IHX whole model at the same location. In case 2 and case 3, the axial velocity was changed and pressure remained the same as case 1.

In order to monitor velocity and fluid force of transverse flow and axial flow in elbow tubes, monitor faces and points were set. Eight tubes were selected as shown in Fig.2. Two were adjacent to inside wall, two were adjacent to outside wall and two were in middle. Eight monitor surfaces with 1mm height were set along axial direction for each tube and one of them was in straight tubes section. The meaning of tubes label in Fig.2 interpreted as follow. The first number was for layer number increasing from inside to outside. The second number was for the location in the layer number. For example, the label 1.1, the first number 1 was for the first layer adjacent to inside wall, the second number was for the location adjacent to periodic wall.

Fig.1 Model of elbow section flow field

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Fig.1 Model of elbow section flow field
As shown in Fig.3, 2 monitor points were set on circumferential and radial respectively. As a result, a total of 64 monitor faces, 256 monitor points and 1152 variables were obtained.

3. simulation results and analysis of flow field

3.1. simulation results
The streamlines in flow field of shell side were shown in Fig.4. The top was inlet and the bottom was outlet. Flow direction varied with the change of structure. When rotation angle of heat exchange tubes changed, the rotation angle of flow direction decreasing with flow was less than that of tubes because of inertia. As shown in Fig.4, the max angle between flow direction and tubes was in the inlet of elbow section. Due to the short length of straight tubes, the flow direction was still impacted by upper elbow tubes. On the whole, the velocity in elbow section was faster than straight section because of flow area decrease caused by the distribution of fluid was mainly in annular region between tube layers.
3.2. change of flow angle

According the simulation results, angle between flow direction and tubes was calculated. In order to verify the accuracy of methods proposed in 1.3, take transverse flow in middle of tube 5.5 simulated by case 1 for instance. As shown in Fig.5, tube 5.5 was marked by red color, and direction vector of transverse flow marked by black line was achieved by data processing methods. As results shown in velocity vector and cloud picture, flow direction changed with elbow section structure, the velocity was faster between tube layers and transverse flow direction was vertical to radial direction. The transverse flow direction calculated by formula in 1.3 was consistent with simulation.

Change of flow angle could be calculated by formula in 1.3. As shown in Fig.6, the angle decreased in elbow section. As the fluid flowed, flow direction tended to be consistent with tubes. Moreover, the angle of inside layers was smaller than outside layers and angle increased with increase of velocity.

![Fig.5 velocity in middle elbow section of tube5.5 in case 1](image)
3.3. transverse flow velocity simulation
Vibration amplitude induced by axial flow was small and impact little on equipment, in general, it could be ignored [4]. Only when velocity was much faster than normal, it will be considered. So, analysis of the transverse flow was main in this paper. Velocity of transverse flow could be achieved by data processing methods in every monitor faces and points. The results of transverse flow velocity changing along axial direction were shown in Fig7.

When the inlet velocity was the same, the change of transverse flow velocity had close relationship with model structure. Before entering the elbow section, transverse flow velocity was small but increased sharply when just flowed into elbow section because of inertia. And angle between flow direction and tubes deceased.

At the same inlet velocity, transverse flow velocity in middle layers were faster than inside and outside layers because of wall resistance.

The different inlet velocity had little impact on change trend of transverse flow velocity along axial direction, but there was a positive correlation between transverse flow velocity and inlet velocity.
Fig7 change of transverse flow velocity in elbow section
(a)-(c) inside, middle and outside tubes in case 1
(d)-(f) inside, middle and outside tubes in case 2
(g)-(i) inside, middle and outside tubes in case 3

4. conclusions
The computational fluid dynamics (CFD) method was used to research the distribution characters in
elbow section of IHX and the numerical calculation model was established in this paper simulating the
flow field with different inlet velocity. The main conclusions were following:
The flow angle and transverse flow velocity were max in inlet of elbow section where structure
changed drastically and decrease with flow. And there was a positive correlation with inlet velocity. The
elbow section should be paid more attention on design, operation and maintenance of the heat exchanger.

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