CFD Analysis for Predicting Flow Resistance of the Cross Flow Gap in Prismatic VHTR Core

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1. Introduction

The core of Very High Temperature Reactor (VHTR) consists of assemblies of hexagonal graphite blocks and its height and across-flats width are 800 mm and 360 mm respectively. They are equipped with 108 coolant holes 16 mm in diameter. Up to ten fuel blocks arranged in vertical order form a fuel element column and the neutron flux varies over the cross section of the core. It makes different axial shrinkage of fuel element and this leads to make wedge-shaped gaps between the base and top surfaces of stacked blocks. The cross flow is defined as the core flow that passes through this cross gaps. The cross flow complicates the flow distribution of reactor core. Moreover, the cross flow could lead to uneven coolant distribution and consequently to superheating of individual fuel element zones with increased fission product release. Since the core cross flow has a negative impact on safety and efficiency of VHTR [1], core cross flow phenomena have to be investigated to improve the core thermal margin of VHTR. In particular, to predict amount of flow at the cross flow gap obtaining accurate flow loss coefficient is important. Nevertheless, there has not been much effort in domestic. The experiment of cross flow was carried out by H. G. Groehn in 1981 Germany [2]. For the study of cross flow the applicability of CFD code should be validated. In this paper a commercial CFD code CFX-12 validation will be carried out with this cross flow experiment. Validated data can be used for validation of other thermal-hydraulic analysis codes.

2. Description of Groehn's Experiment

The experiment was designed to represent the flow conditions of two stacked fuel elements. Air at normal temperature and pressure is used as working fluid. The scaling ratio of model to reference is 1.0. From the core data given in Table I, Reynolds numbers were calculated to range from $4.2 \times 10^4 \leq Re \leq 1.6 \times 10^5$. The Reynolds number was based on the coolant channel data. For experimental purposes the coolant channels of two stacked fuel elements were simulated by steel tubes glued at their extremities into hexagonal flanges. Between the inner flanges of the test section, steel plates could be mounted with the same number of coolant channels as the fuel block models. One surface of the steel plates was sloping so that a wedge-shaped gap was formed between the plate itself and one of the flanges. Test gap widths were 1.85, 3.75, and 6 mm. The cross flow was inserted through 12 holes arranged around one of the flanges.

Table I: Core and Fuel Element Data

Static pressure at core entry, bar	$p = 60$
Core pressure drop, bar	$\Delta p_{core} = 1 \ldots 1{,}2$
Gas inlet temperature, ℃	$T = 500$
Gas outlet temperate, ℃	$T = 800$
Coolant	Helium
Coolant velocity depending on core depletion, m/s	$u_K = 20 \ldots 80$
Length of a fuel element, m	$L = 0.8$
Across-flats width, m	$s = 0.36$
Coolant channel diameter, m	$D = 0.018$
Number of coolant channels	$Z = 72$
Maximum gap width, m	$A = 6 \times 10^{-3}$

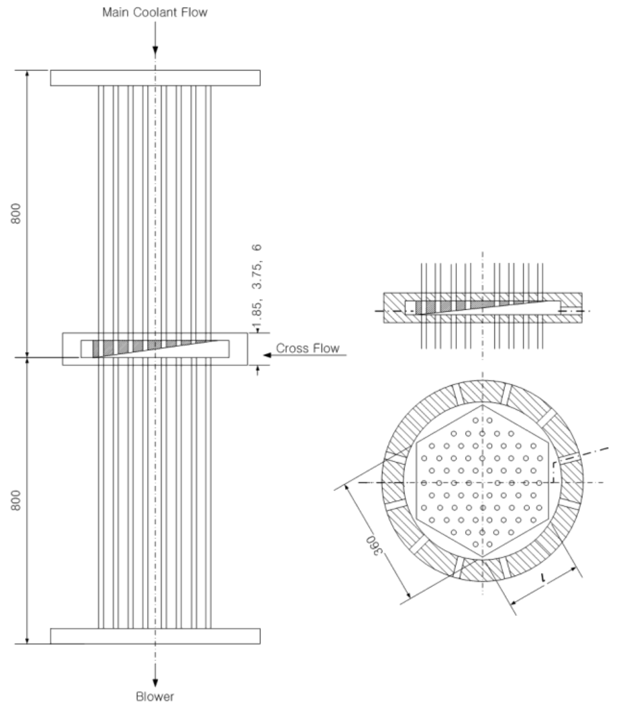

Fig. 1. Experimental Setup of Groehn's Experiment

3. CFD Analysis Conditions

CFX-12 was used for validation CFD code and it was validated by comparing the simulation results with the experimental data. Figure 2 shows a computational domain and the mesh structure of gap width 6 mm case. In present simulation, 4 million nodes of hexahedra mesh were used. The working fluid is air at normal temperature and pressure. Shear Stress Transport (SST) model based on the Reynolds Averaged Navier-Stokes (RANS) equation is adopted for turbulence closure. And upwind scheme was implemented for the convective terms.

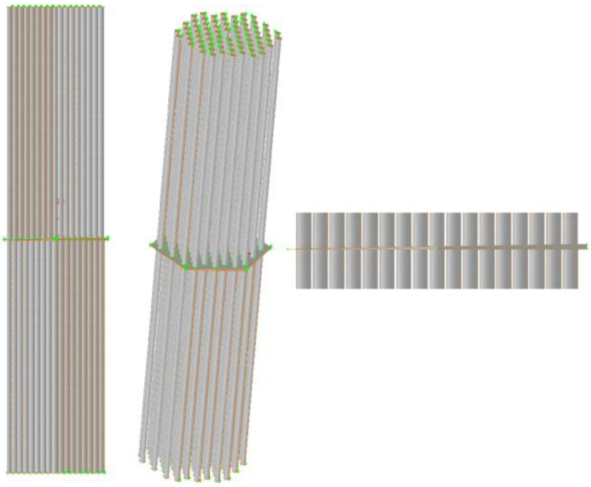

Fig. 2. Computational domain and the mesh structure of gap width 6 mm case.

3. Results and Discussions

Figure 3 shows the experimental data. The CFD analysis will be performed according to following conditions and data.

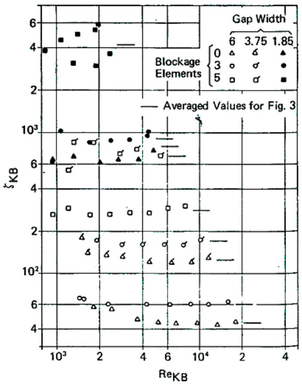

Fig. 3. Flow resistance of the gap

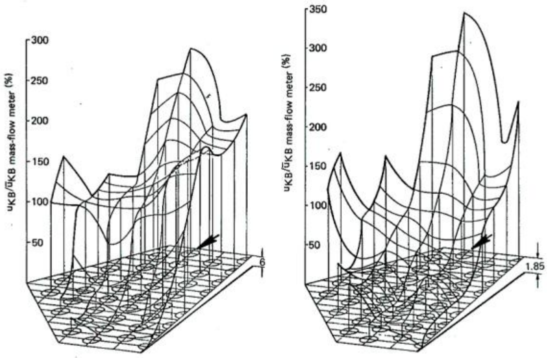

Fig. 4. Velocity distribution under cross flow

The main coolant flow was reduced exactly by the amount of the added cross flow. And consequently no influence on the velocity distribution was measured in the downstream block. This means that the main coolant flow in the upstream block suffers a reduction of the amount of the cross mass flow added in the gap. CFD analysis will be validated with these results.

4. Conclusions

In short, the influence of cross flow affects the upstream block mostly, whereas the downstream block is not much affected by it. CFD analysis using CFX-12 will be carried out to validate with cross flow experiment and investigate cross flow phenomena. The calculated cross flow loss coefficient can be used for making thermal-hydraulic analysis codes. Furthermore, it is expected to be used for study to secure safety and evaluate the thermal margin of VHTR core.

REFERENCES

[1] INEEL, Design Features and Technology Uncertainties for the Next Generation Nuclear Plant, INEEL/EXT-04-01816, 2004.

[2] H. G. Groehn, Estimate of Cross Flow in High Temperature Gas-cooled Reactor Fuel Blocks, Heat Transfer and Fluid Flow, Nuclear Technology Vol. 5, 1982.