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A Benchmark CFD Calculation for a Cross Flow between Fuel Blocks of a Prismatic VHTR

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1. Introduction

The computational fluid dynamics (CFD) technology has been successfully applied to many industrial engineering areas such as aircraft and vehicles. However, it is generally accepted that the CFD codes, even if they are commercial ones, require more sufficient validations to apply to the analysis and design of a very high temperature reactor (VHTR) [1]. One of the interesting phenomena of a prismatic VHTR is a cross flow between fuel blocks of a prismatic reactor. The CFD simulation of the phenomena is complex since laminar to turbulent transitions occur around the cross flow gap. It is considered that any turbulence model has not been generally accepted yet for laminar to turbulent transitions and their mixture flows.

In this work, a CFD benchmark calculation has been made against the JAEA experiment [2] to investigate the applicability of the existing CFD technology to a cross flow phenomena in fuel blocks of a VHTR.

2. JAEA Experiment

Four graphite blocks were stacked up in a column (total height = 2.281 m) and were surrounded by the steel shroud to simulate the bypass gap between fuel columns, as shown in Fig. 1. The simulated bypass gap width between the block and the shroud was 1.2 mm and the shroud was equipped with static pressure taps. The hexagonal fuel block has 12 coolant holes with 20 mm in diameter. The flat-to-flat distance of the block is 299 mm. One artificial cross flow gap (~1 mm) was created in the middle of the column to simulate a vertical gap between fuel blocks. The experiment was performed for a parallel gap as well as a simulated wedge-shaped gap. The channels were connected to a blower. The air at atmospheric pressure was drawn from the top and flowed down the channels and the bypass gaps. The static pressure tube (~3 mm in diameter) was inserted into each coolant channel from the top.

3. Benchmark CFD Model

A commercial CFD code, CFX 11 [3], is used for the present work. The case with the uniform cross flow gap size of 1 mm is selected for the benchmark calculation. Fig. 2 shows the flow characteristics in the test section. The experimental data by JAEA confirmed that the flows in the bypass gap and the cross gap are laminar but the coolant channel flow is turbulent. Therefore, laminar and turbulent flows are mixed together around the cross flow gap. In this work, the SST turbulence model is applied to all the fluid regions assuming all the flows are turbulent. Such an assumption might be useful because commercial CFD codes can be applied without any modifications for the transitions between the laminar and turbulent flows.

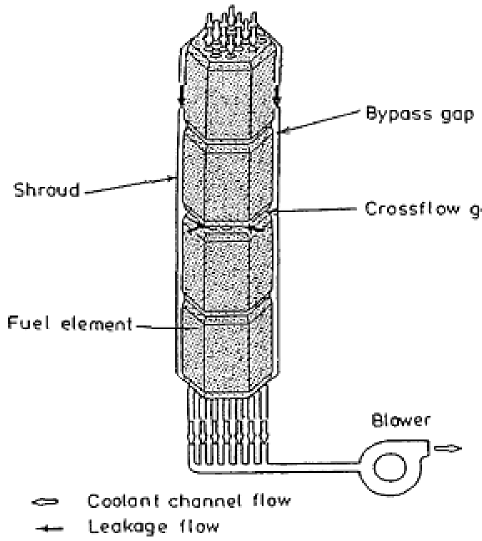

Fig. 1. JAEA's cross flow experiment [2].

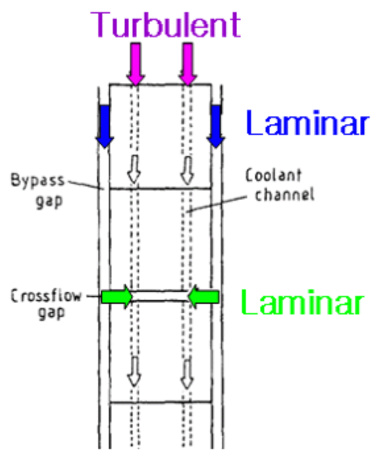

Fig. 2. Flow characteristics in the test section.

Three sets of the computational grids are generated to investigate the grid sensitivity of the CFX results. The total number of the reference grids is ~2.4 millions. The fixed mass flow rate is specified at the outlet flow and the opening boundary condition is imposed on the inlet.

4. Results and Discussions

Fig. 3 shows the calculated velocity contour by CFX 11 at the cross flow gap. It shows fast streams of the coolant channel flows. The bypass gap flow is much slower. A significant velocity changes exist at the cross flow gap. The central part of the cross flow gap has a wide stagnant region due to symmetry. The calculated average Reynolds numbers at the coolant channel, the bypass gap, the cross flow gap are ~49000, ~1900, ~1800, respectively.

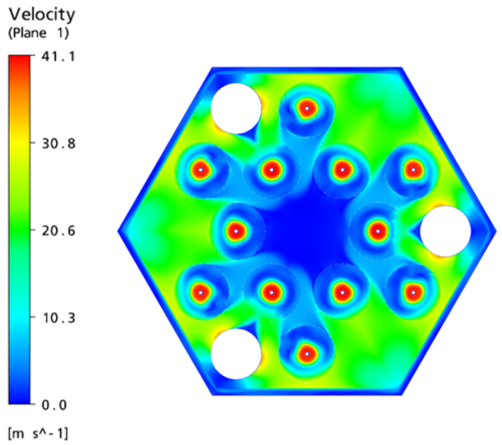

Fig. 3. The calculated velocity contour at the cross flow gap.

Table I shows the comparison of the present CFX results with the experimental and calculation results by JAEA. The table shows an excellent agreement of the present calculation with the experimental data of JAEA. In the prediction of the bypass flow fraction, the difference is less than 10%. The CFX results in Table I are from the case of the reference grid size. The CFX calculations with the other grid sizes showed that there is no significant impact on the presented results.

Table I. Comparison with the results by JAEA

	JAEA Data [2]	Present CFX results
Coolant channel ΔP[a)] (kPa)	4.94 [b)]	4.93
Bypass gap ΔP [a)] (kPa)	2.08 [b)]	2.03
Bypass flow fraction (%)	9 [c)]	9.8

[a)]Pressure difference across 4 fuel blocks.
[b)]Digitized value of experimental data.
[c)]Calculated value by JAEA.

Fig. 4 shows the comparison of the predicted static pressure distribution with the measured one. It also shows a nice agreement. Therefore, it is concluded that the CFD model used in the present work can reasonably simulate the JAEA experiment although the turbulent flow is assumed for all the fluid regions. In the prediction of the JAEA experiment, the measurement device for the static pressure needs to be modeled to enhance the accuracy of the CFD calculation. It is found by additional calculation that the pressure drop can be under-estimated by ~10% if the static pressure tube is neglected in the CFD model.

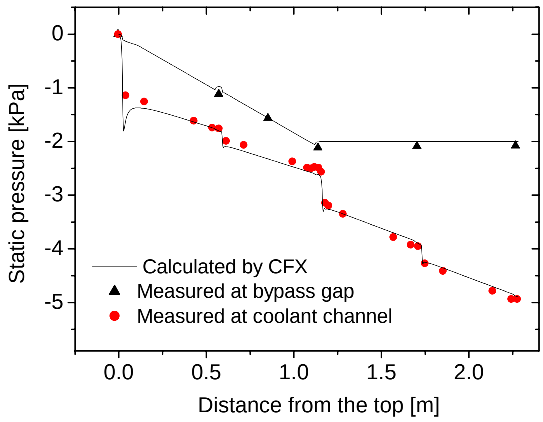

Fig. 4. The predicted and measured static pressure distribution.

5. Conclusions

A benchmark CFD calculation was carried out for a cross flow between fuel blocks of a VHTR against the JAEA experiment. The results of the calculation show that the present CFD model can reasonably predict a cross flow even though the SST turbulence model is applied to the bypass gap and the cross gap whose flows are laminar. It should be noted, however, that the present results are limited to isothermal flows. Thermal behavior at the cross flow gap has to be assessed for more practical applications.

ACKNOWLEDGMENTS

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