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A review on the coupling of CFD code into system analysis code in Gas Cooled Reactors

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1. Introduction

The High Temperature Gas-Cooled Reactor (HTGR) is a promising alternative for Generation IV reactors. A system analysis unresolved solution technique considers the characteristics of local thermal-hydraulic phenomena of coolants, such as non-symmetric mixing of helium in and around the upper and lower plenum of the reactor. A key is the efficient implementation of computational fluid dynamics (CFD) code into system analysis code. This paper presents a review and reasoning process of adaptation of a CFD code to a system code for gas cooled reactors, such as HTGR, MHTGR.

2. Need to couple CFD code

Coupled codes, which include types of codes to analyze different phenomena about reactor physics, fuel behavior, thermal-hydraulics (T/H), containment, and structures, provide the results of interactions between different physical phenomena [1]. One coupled methodology is CFD, which provides detailed insight into local phenomena, coupling into system code. CFD codes are typically used to model multi-component distribution and mixing phenomena [2].

The mixing problem at the high-temperature engineering test reactor (HTTR) in gas cooled reactor[figure 1] occurs if the coolant is not mixed to a uniform temperature in the hot plenum. The temperature difference in the coolant flow may cause hot spots in high-temperature components, such as the intermediate heat exchanger (IHX) and the pressurized water cooler (PWC) installed downstream from the core [3]. The temperature of coolant helium gas collected from each fuel region is not uniform, because the power rate in fuel regions is different in each fuel region [4].

Determination of a coupled solution between CFD and system code is presented. A thermal mixing effect was suggested [5, 6].

The thermal mixing of coolant exiting the core into the outlet plenum is one of the identified design issues for the VHTR [7]. An understanding of complex and three-dimensional flow patterns is important because of hot streaking, which can give thermal stripping and hot spots in the plenum structure and power conversion unit (figure 2) [7].

3. Approach to couple CFD code

3.1 Identification of differences between system code and CFD code

The RELAP5-3D systems analysis code and FLUENT CFD code momentum equation formulations were compared to show the definite need and required capability of CFD code (table I) [6, 8]. A simple test case with a 3D pipe was simulated to demonstrate differences between the two codes, especially around the wall region [8].

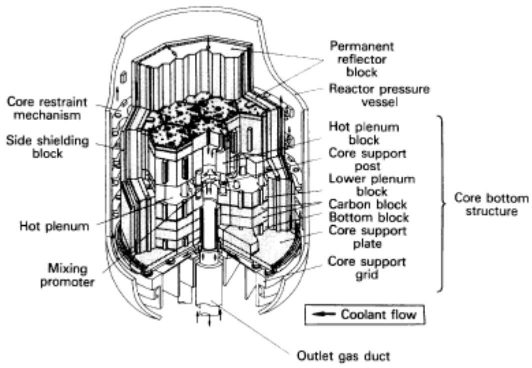

Fig. 1. General view of the HTTR core bottom structure [3].

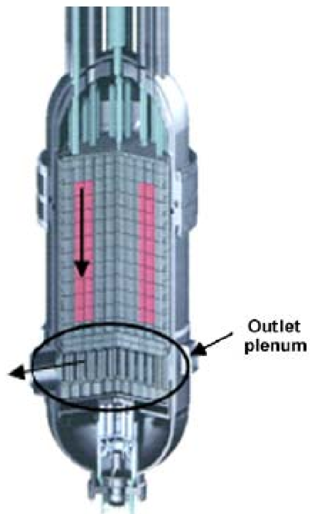

Fig. 2. VHTR schematic (GA, 2003). The location of the outlet plenum is indicated. The flow direction is indicated by the arrows [7].

3.2 Coupling model and information exchange

Coupling model

Each model from each code is a initiating point to start coupled analysis for coupling to interlink system code and CFD code. Conventional nodalization was used to generate the boundary condition for the CFD code (figure 3). The CFD code calculation was done in complex geometric meshes from this boundary condition (figure 4) [5, 7].

Information exchange

The messenger linking CFD and system code was an Executive program, such as the Parallel Virtual Machine (PVM) [6], with reference to a semi-implicit coupling methodology [11].

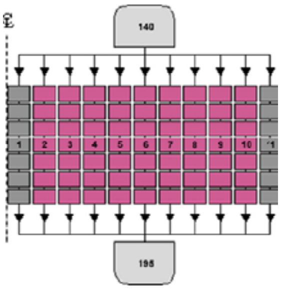

Fig. 3. The nodalization for system [7].

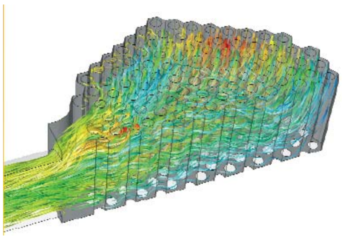

Fig. 4. 3D geometry and result by CFD [5].

Table I: Comparison of Fluent & RELAP5-3D Capabilities (summarized from [6])

S/W	Single-Phase		Two-Phase	
	1-D	2-or 3-D	1-D	2-or 3-D
Fluent	Not used	Preferred	Not used	Superior for specialized applications
RELAP -5D	Preferred	Input assumption and required	Preferred	For analyses of integral system behavior

4. Reasoning process

A procedure is presented as a guideline for implementation of the CFD code into the system analysis code, from the results of review.

1. Need to couple CFD code
   Any lack in performance or preference for improvement of "system analysis code" is defined qualitatively and/or quantitatively by using a method, such as scoping analysis, PIRT.
   .
2. Coupling methodology
   Time: A long term calculation requires days for the gas cooled reactor [9, 10]. The CFD coupled code gives results that can be used with limited sources, such as computing power and time.
   Stability: The improved should have a capability to give a well-stabilized solution.

   Reality: Where are the interfaces for exchanging thermal-hydraulic properties for a extremely complex 3D configuration of reality.

3. Selection of CFD code candidates
   The following are possible trees of step for selection:
   - Commercial or house CFD code
   - What dimension
   - What mesh types
   - How to treat mixing and/or turbulent flow

4. Verification strategy
   Both conservation and effectiveness of coupled solution should be verified.

5. Conclusions

Coupling CFD into system code contributes to the performance and safety calculation that considers local mixing effects. A tentative reasoning process is proposed to develop specifications related to the coupling of a CFD code into a system code.

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