Multi-Physics simulation for Nuclear Reactor core by CUPID and DeCART coupling

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1. Introduction

KAERI has been developing a component-scale thermal hydraulics code, CUPID and neutron kinetics code, DeCART. For a multi-scale analysis, the CUPID is on course to merge into a system-scale thermal hydraulic code, MARS [1]. In multi-physics viewpoints, both codes has been accessed with other codes. CUPID code has been coupled with assembly-wise neutron kinetics code, MASTER [2] and simulated hypothetical transient scenario such as CEA drop/ejection accidents. DeCART code has been co-simulated with subchannel thermal-hydraulics code, MATRA for design of small modular reactor [3].

In the present paper, a multi-physics simulation was performed by coupling CUPID with a three dimensional pin-wise neutron kinetics code, DeCART. Supervisory server program organize two codes with socket communication with TCP/IP. OPR1000 nuclear reactor core was simulated. The following sections present the numerical modeling for the reactor core, coupling of the kinetics code, and the simulation results.

2. Numerical Methodology

2.1 Coupling strategy

Fig 1 shows variables to be transferred to the other codes. Basically power output of fuel assembly is calculated from DeCART and transferred to CUPID. Since CUPID calculates thermal-hydraulics of coolant, coolant temperature, density and void fraction are provided into DeCART input. In addition, fuel temperature as well as cladding's outer temperature are obtained by CUPID so that these variables also transferred to the DeCART.

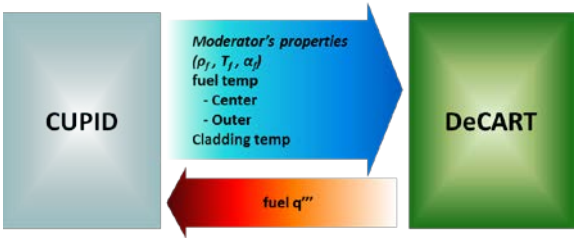

Fig 1. Variables to be transferred between CUPID and DeCART

In order to run two codes simultaneously, network socket are utilized. The variables to be delivered between CUPID and DeCART are directly transferred from one to the other through a network socket. The independent supervisory program controls the data transfer. The coupling procedures by the socket are shown in Fig 2. The supervisory program is ready for the socket and stands by. The coupled variables are transferred from each code to the server program as soon as the two codes are ready. The CUPID and DeCART starts to execute the calculation separately after the transfer of the coupled variables from server program is completed. If either or both codes are converged or reached at limited iterations, the code waits for the other to be converged or reach limited iterations. After each iteration of the two codes is completed, the common variables to be coupled are updated by the server program through the network socket, and these procedures are repeated.

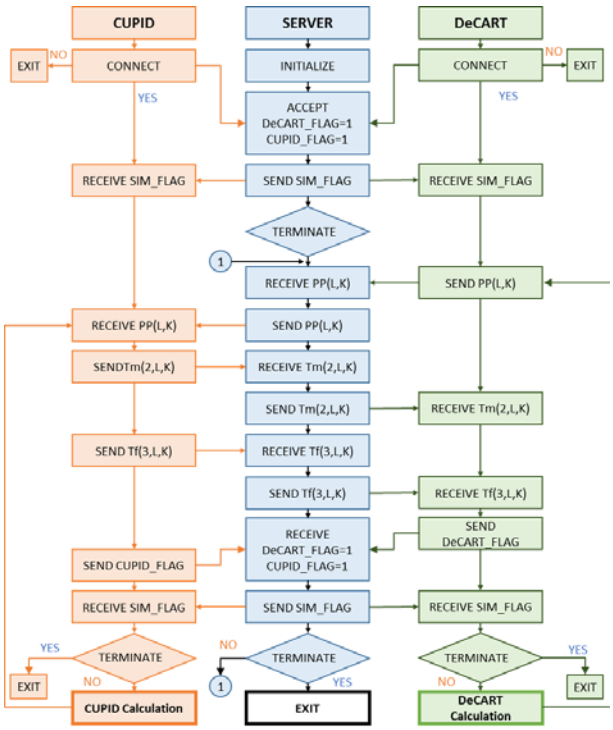

Fig 2. MPI communication

2.2 Reactor core modeling

For a better estimation of this simulation, the OPR1000 reactor vessel was employed. In DeCART

calculation fuel assembly as well as outer reflector area were modeled. However, CUPID takes into account only fuel assembly region. For radial discretization, every single cell is assigned to model each fuel rod. Thus 45,312 meshes are used for CUPID and 61,696 for DeCART. To avoid complexity of general mapping between two codes, the number of axial mesh are identical. Overall 26 meshes are adopted along reactor height. Totally 1,178,112 and 1,604,096 meshes are assigned for CUPID and DeCART code, respectively.

2.3 Pressure drop model

To simulate thermal-hydraulics in the fuel assembly region, a porous media approach was adopted. The porosity of the fuel assembly region is at about 0.54, and the permeability at the horizontal direction within the porous media is assumed to be unity, whereas the permeability at the axial direction is assumed to be the same as the porosity.

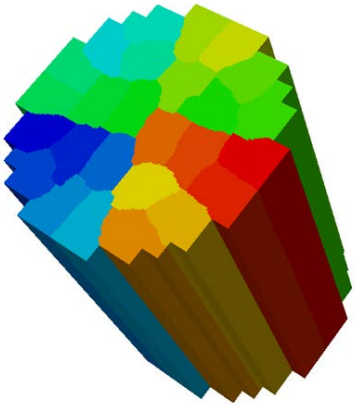

Fig 3. Domain decomposition for CUPID calculation

3. Results and Discussion

3.1 Simulation results

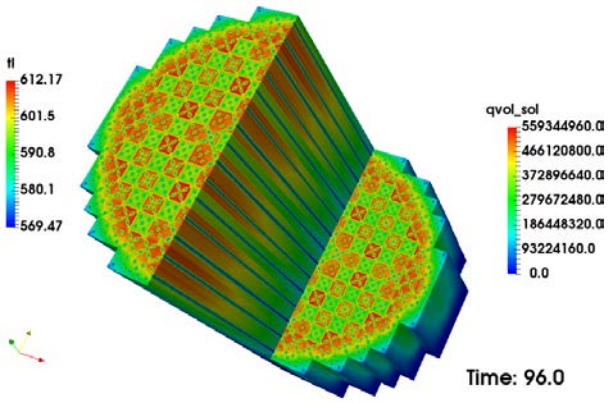

Fig 5. Steady state for normal operation

In this study, the two-phase flow behavior inside separator is calculated according to the different inlet velocity; 1.0 m/s and 5.0 m/s of gas velocity is assigned. The boundary condition about void fraction and quality level at inlet during normal operation are set to be constant; 0.92 for void fraction and 25% quality, respectively. Design specification at the exit is supposed to be less than 99.75%. The result from the CUPID simulation shows reasonable range.

The liquid-gas mixture travels through a short vertical section and is redirected by the top plate to the swirl vane. The vanes impart a centrifugal force to the mixture. In a vortex motion, liquid flows up to inner wall and the gas tends to rise in the center of the separator. Most portion of the liquid exists through the vertical perforated wall, and the gas flows through the top exit plate.

Flow field for different inlet velocity is shown in Fig 4 and 5. Since larger inlet momentum of the mixture can converted higher level of swirl strength, liquid fraction of the mixture for high velocity tends to separate the liquid from the mixture easily. For relatively lower velocity inlet condition (1 m/s), more liquid fraction is captured in the middle of the separator.

4. Conclusions

The reactor core was numerically investigated by the coupled calculation with thermal-hydraulics code, CUPID and neutron kinetics code, DeCART. Co-simulation was controlled by supervisory program which calls two codes with MPI communication. For thermal-hydraulics analysis, porous media approach was adopted and corresponding pressure drop models such as friction and turbulent mixing were considered. Steady state of normal operation for OPR1000 reactor was taken into account.

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