Verification Methods of Pressure Matrix Integration and Reduction for Implicit Coupling of Two Codes

Kum Ho Han[a*], Bub-Dong Chung[a], Soon-Joon Hong[a], Jaeseok Heo[b],
[a]*FNC Tech., Heungdeok IT Valley, Heungdeok 1-ro, Giheung-gu, Yongin-si, Gyeonggi-do, 446-908, Korea*
[b] *Korea Atomic Energy Research Institute, 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 305-353, Korea*
[*]Corresponding author: khhan0529@fnctech.com

Keywords : Implicit Coupling, Pressure Matrix

1. Introduction

For more stable coupled calculation of SPACE domain and CAP domain, an implicit coupling algorithm is now under development. SPACE is a system analysis code, and CAP is a containment thermal hydraulic analysis code. Two codes are already explicitly coupled to interactively calculate the break flow and backpressure.

The key of Implicit Coupling lies in coupling the pressure matrices of the two codes to ensure that the velocities of the coupled junctions are calculated identically, while appropriately accounting for pressure changes caused by each code. Previous research [1] proposed a method for solving the coupled pressure matrix and verified its effectiveness using a single code (CAP code). This study applies the proposed method to the coupling of SPACE and CAP codes.

2. Integration Pressure Matrix and Reduction

Fig. 1 shows the nodalization of SPACE/CAP, highlighting connections between specific nodes. Fig. 2 presents the integrated pressure matrix that needs reduction for computational compatibility. To match the matrix with CAP's domain, pressure data from SPACE nodes 5 and 13 must be substituted with nodes 2 and 4. Additionally, pressure differences from nodes 5 and 13 can be replaced with those from nodes 2 and 4. This approach allows the integrated pressure matrix to be converted into two reduced matrices, as illustrated in Fig. 3.

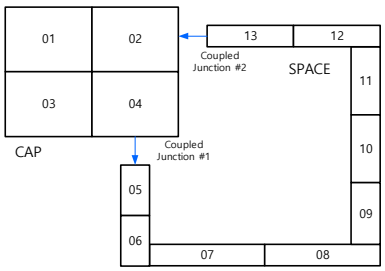


Fig. 1. SPACE/CAP sample nodalization

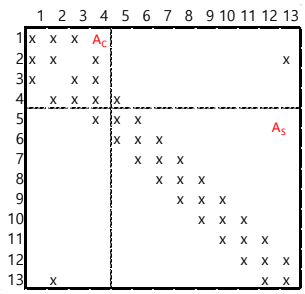
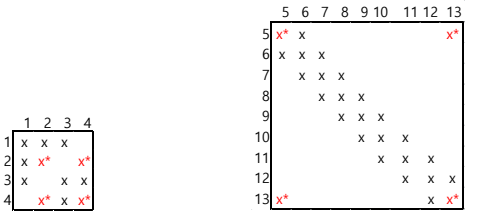


Fig. 2. Integrated pressure matrix of SPACE/CAP



(a) Pressure matrix of CAP (b) Pressure matrix of SPACE

Fig. 3. Reduced pressure matrix of each code

3. Verification Problem

Referring to previous research [1], SPACE-CAP implicit coupling was implemented. To verify this study, conceptual problems were solved where mass transfer occurs frequently between the coupled domains.

Figs. 4 and 5 illustrate the verification problem. Both cases consist of 10 volumes; Figure 1 features vertical connections, while Fig. 5 showcases horizontal connections. Each cell is filled with pure steam, and the thermodynamic conditions for each cell are presented in Table I.

Table I: Conceptual Problem Condition

No	P [bar]	T [K]	V [m^3]
01	3.0	1000.0	9.0
02 ~ 10	1.0	1000.0	1.0

Fig. 6 illustrates the computational domains of SPACE and CAP to calculate Problem 1 implicitly. Similarly, for the coupled analysis of Problem 2, the computational domain was divided as depicted in Fig. 7.

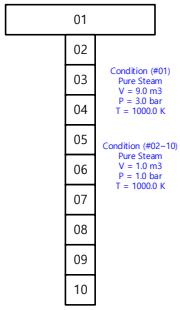


Fig. 4. Conceptual Problem #1

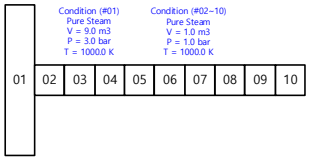


Fig. 5. Conceptual Problem #2

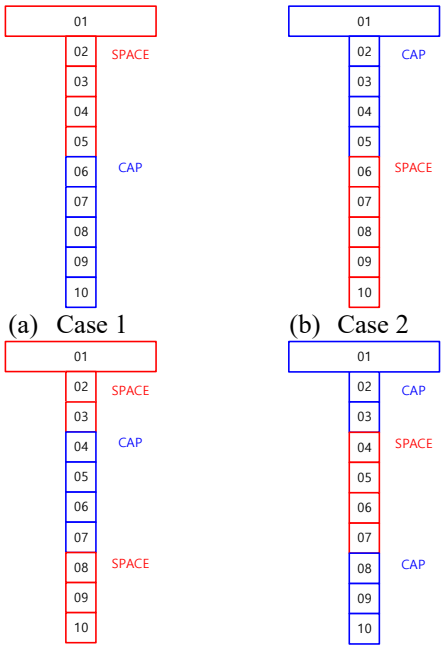


Fig. 6. Calculation Domain of Conceptual Problem #1

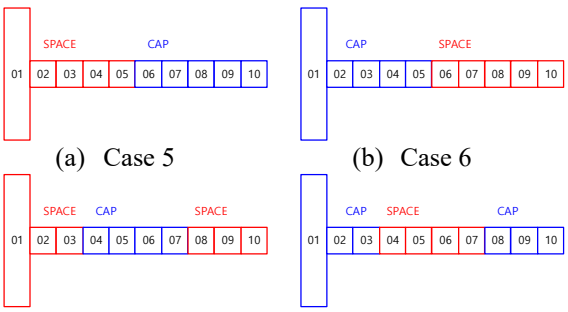


Fig. 7. Calculation Domain of Conceptual Problem #2

4. Verification Results

Figs. 8 to 10 present the calculation results for Case 4, while Figs. 11 to 13 illustrate the results for Case 8. Within 0.4 seconds, the material in cell 1 moves to connected node, resulting in pressure changes at each node, and the steady state is reached after approximately 0.4 seconds (Figs. 8, 11). It is confirmed that CAP and SPACE calculates the velocities at the coupling junctions equivalently (Figs. 9, 10, 12, 13).

Table II compares the steady state pressures from Case 1 to Case 8. Although differences in steady state pressure are observed depending on the computational domain, the pressures generally converge to similar values. Notably, there is a distinction between Case 1 (or Case 5) and Case 2 (or Case 6). In case of Cases 1, 5 the materials exit from the SPACE domain, whereas in case of Cases 2, 6, the materials exit from the CAP domain. It is shown that when material exits from SPACE, the steady state pressure is lower than when it exits from CAP, which is attributed to differences in the PV terms associated with material inflow in the two codes.

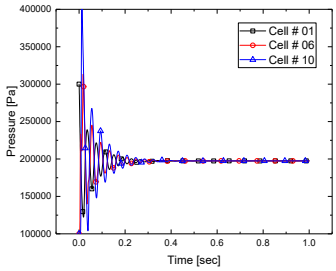


Fig. 8. Pressure Behavior of Case 4

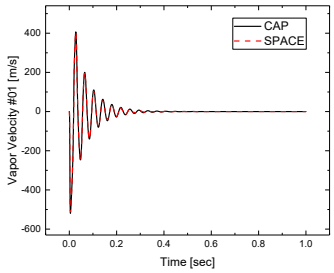


Fig.9. Vapor Velocity (Cell 03-04) Behavior of Case 4

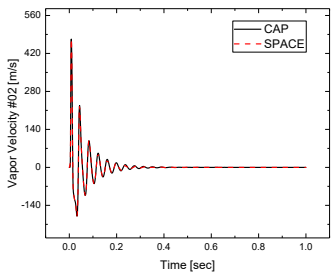


Fig. 10. Vapor Velocity (Cell 07-08) Behavior of Case 4

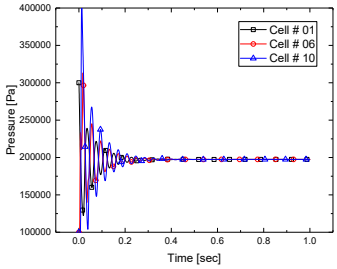


Fig. 11. Pressure Behavior of Case 8

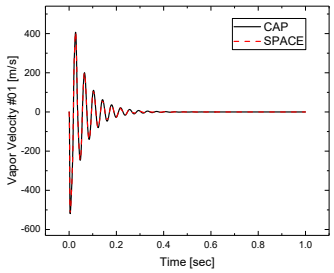


Fig.12. Vapor Velocity (Cell 03-04) Behavior of Case 8

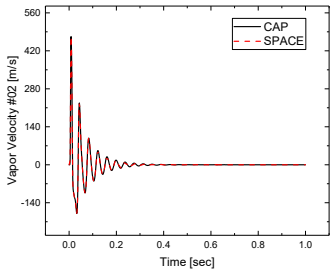


Fig. 13. Vapor Velocity (Cell 07-08) Behavior of Case 8

Table II: Steady State Pressure

No	P [bar]		
	Coupling	CAP Alone	SPACE Alone
Case 1	1.95686	1.99404	1.93550
Case 2	2.00157		
Case 3	1.98305		
Case 4	1.98070		
Case 5	1.95696	1.99414	1.93561
Case 6	2.00179		
Case 7	1.98297		
Case 8	1.98074		

5. Conclusions

In this study, implicit coupling of SPACE-CAP was implemented. This coupling method expected to result in faster coupling speeds compared to the existing explicit coupling. Furthermore, this method is anticipated to be useful in long-term cooling analyses where two-way flow occurs between the two codes

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT). (No. 00144494)

REFERENCES

[1] K. H. Han, B. D. Chung, S. J. Hong, and J. S. Heo, Verification Methods of Pressure Matrix Integration and Reduction for Implicit Coupling of Two Codes Using One Code, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 9-10, 2024.