GAMMA-FR validation against adiabatic expansion of hydrogen

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1. Introduction

KAERI (Korea Atomic Energy Research Institute) Nuclear Fusion Technology Development Division is developing in-house safety analysis code for fusion system, which is called GAMMA-FR (General Analyzer for Multi-component and Multi-dimensional Transient Application-Fusion Reactor) code [1]. KO TBM team use this code for safety analysis of the HCCR TBS which is going to be installed in ITER. ITER safety division provided list of validation requirements which should be satisfied for the quality assurance of safety analysis code. Many verification and validation items of GAMMA-FR have been performed by KAERI [2,3] and this paper is the one result of them, which is validation against adiabatic expansion of hydrogen. Analytic assessment was done and code to code verification is included in this paper.

2. Description of the problem

The problem consists of two control volumes that are pressurized with hydrogen such that the pressure in volume 1 is greater than that in volume 2. At time zero, a flow path is opened between the two control volumes, and hydrogen from the higher-pressure control volume expands into the lower-pressure control volume until the two pressures equilibrate. Six cases were analysed, according to the specifications given in Table 1. For this paper we have presented full results for the first case (Case 1) only, though the adiabatic pressure response is shown for all cases.

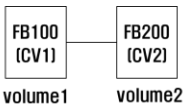

Figure. 1 Schematics of the problem

Case No.	Volume 1 (m^3)	Volume 2 (m^3)	T(I=2) (K)	P(1) (Pa)	P(2) (Pa)	Flow Area (m^2)	Loss Coeff.
1	1000.	1000.	300.	2.0e5	1.0e5	0.05	2.0
2	1000.	1000.	300.	5 0e5	1.0e5	0.05	2.0
3	100.	1000.	300.	2.0e5	1.0e5	0.05	2.0
4	10000.	1000.	300.	2.0e5	1.0e5	0.05	2.0
5	1000.	1000.	300.	2.0e5	1.0e5	50.0	2.0
6	1000.	1000.	300.	2.0e5	1.0e5	0.05	0.1

Table. 1 Validation Cases

3. Analytical Solution

Assuming adiabatic flow and treating hydrogen as an ideal gas, analytic expressions for the control-volume temperatures and pressures, as transient functions of the mass transferred are:

$$T_1 = T_{1o}\left(\frac{m_1}{m_{1o}}\right)^{\gamma-1}$$

$$P_1 = P_{1o}\left(\frac{m_1}{m_{1o}}\right)^{\gamma}$$

$$T_2 = \frac{m_{2o}T_{2o}}{m_2} + \frac{m_{1o}T_{1o}}{m_1}\left[1-\left(\frac{m_1}{m_{1o}}\right)^{\gamma}\right]$$

$$P_2 = P_{2o} + \frac{V_1}{V_2}\left[1-\left(\frac{m_1}{m_{1o}}\right)^{\gamma}\right]$$

T_N = temperature [K] in volume N,
T_{No} = initial temperature [K] in volume,
P_N =pressure [Pa] in volume N,
P_{N0} = initial pressure [Pa] in volume N,
m_N mass [kg] of hydrogen in volume N,
m_{No} = initial mass [kg] of hydrogen in volume N,
V_N = volume [m^3] of volume N, and
γ = the ratio of specific heats for hydrogen (taken to be 1.4).

3. Results

Results from GAMMA-FR and MELCOR for the pressures and temperatures in both control volumes, as a function of the mass remaining in the donor cell, are compared to each other in Figure 5 and 6. According to MELCOR manual volume 3[4], MELCOR calculation result is almost identical with analytical solution, therefore, result of two codes (GAMMA-FR and MELCOR) are compared in this paper and the agreement is very good. The slight differences sometimes visible are in part due to using temperature dependent heat capacities in GAMMA-FR and MELCOR, which introduces some minor deviations from the ideal gas assumption in the analytical solution, and partly due to the time-step selection. Plots of the time-dependent temperatures, pressures, and control volume masses are presented in Figure 2 through Figure 4; all the figures show good agreement between all codes.

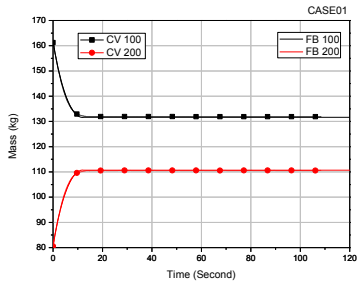

Figure. 2 Calculated Mass vs Time (case 1)

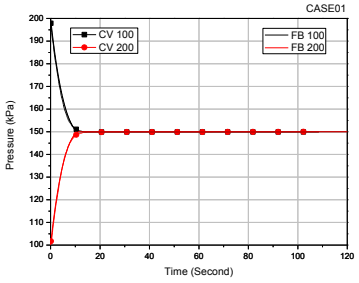

Figure. 3 Calculated Pressure vs Time (case 1)

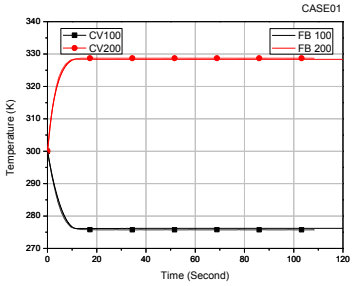

Figure. 4 Calculated Temperature vs Time (case 1)

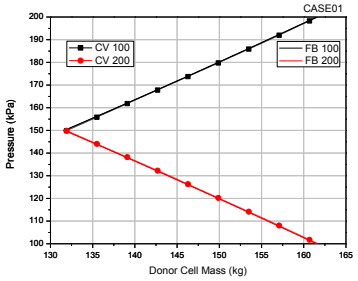

Figure. 5 Pressure vs. Donor Cell Mass (case 1)

6. Conclusion

These results show good agreement among GAMMA-FR, MELCOR predictions and analytical solution, demonstrating GAMMA-FR's ability to predict the adiabatic expansion of a noncondensable gas. The slight differences sometimes visible are in part due to using temperature dependent heat capacities in GAMMA-FR, which introduces some minor deviations from the ideal gas assumption in the analytical solution, and partly due to the time-step selection. No significant differences were found.

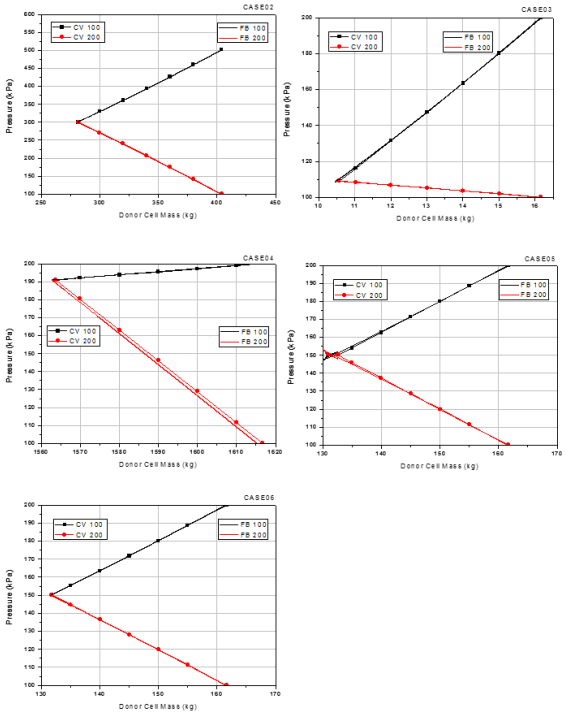

Figure. 6 Pressure vs. Donor Cell Mass (case 2~6)

7. Acknowledgement

This work was supported by the R&D Program through the National Fusion Research Institute (NFRI) funded by the Ministry of Science and ICT of the Republic of Korea (NFRI-IN1803).

8. References

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