Simulation of high pressure steam boosting for functional test of Nuclear equipment

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1. Introduction

In general, active mechanical equipments used in nuclear power plants must pass functional qualification to ensure the safe operation of a nuclear power plant, which is legally compelled by the Announcement of Ministry of Education Science and Technology in Korea [1]. According to the announcement, the functional qualification of nuclear mechanical equipments should be performed based on the standard code of KEPIC MF (ASME QME-1) [2,3], which includes the functional qualification requirements for active valve assemblies for nuclear power plants. The feasibility of the functional qualification can be considered under the high performance facilities which facilitate functional tests of a wide range of nuclear mechanical equipments. Until now, Korea Institute Machinery & Materials (KIMM) has been preparing the high performance facilities of functional test of steam equipments as National R&D Project [4]. The facilities are composed of several main facility components to realize high performance condition of the pressure and temperature corresponding to Nuclear Power Plant. One of the main components is a pressure storage vessel containing high pressure saturated steam required in functional test. The technology of the high pressure steam boosting is considered to be valuable for more efficient storage and release of steam. This paper investigates the effect of steam boosting by simulation of high pressure steam boosting for functional test of nuclear equipment.

2. Methods and Results

This section describes the concept of high pressure steam boosting and introduces the numerical model for steam boosting simulation. The simulation summarized the transient results of fluid field, pressure, temperature and mass fraction.

2.1 High pressure Steam boosting

The basic concept of steam boosting is that lower pressure steam is pressurized by the push of the higher pressure air. The steam boosting analysis is depicted in Fig.1. The left tank initially contains the only saturated steam at 180 bar, and the right tank has the only air at 200 bar. If opening an on/off valve on the connection pipe, the steam in left tank is instantly going to be pressurized by the higher pressure air. So, the both pressures of steam and air will be converged to an equilibrium pressure. After equilibrium, the injection of the air through the above right inlet will boost and push the steam in the left tank to the above left outlet.

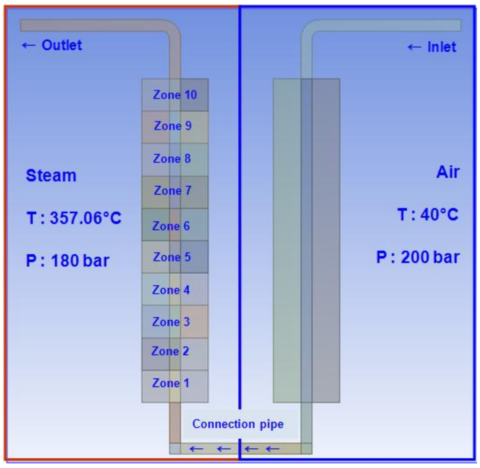

Fig. 1. Sketch for High pressure steam boosting analysis

2.2 Numerical model of steam boosting

The steam boosting simulation requires a numerical technology of computational fluid dynamics (CFD) with two species of steam and air. This paper used the commercial CFD software as ANSYS Fluent [5]. The two dimensional numerical model like Fig.1 was built up by mesh sensitivity test of pre-processor. The number of finite control volumes is about 115,000.

The governing equations include the four kinds of conservation equations such as continuity, momentum (Navier-stokes equation), species and energy. The standard k-ε model was also utilized for turbulent analysis. The transient simulations with the above governing equations are performed based on the algorithm of control volume method as the most well-known CFD technology.

The boundary condition is defined that the left tank has the saturated steam at 180 bar and the right tank is full of the air at 200 bar. The left tank is divided to ten regions for the detailed evaluation of mass fraction.

This simulation investigates the steam boosting effects by visualizing internal fluid field such as velocity, pressure and temperature, and mass fraction of each species.

2.3 Result of steam boosting in closed system

The first simulation is the transient result of steam boosting in closed system, as Fig. 2-4. These results show that the three zones of 8-10 are regarded as the effective zone according to the appropriate temperature and mass fraction (humidity) for 180 min.

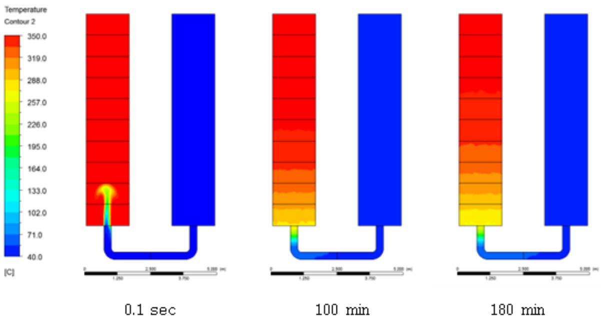

Fig. 2. Temperature distribution in closed system

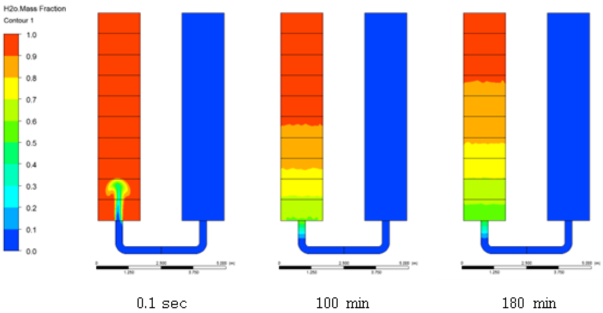

Fig. 3. Steam mass fraction distribution in closed system

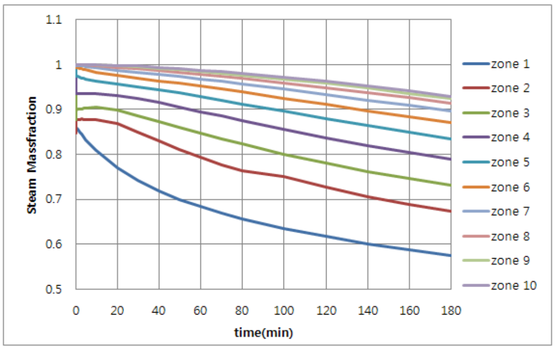

Fig. 4. Steam mass fraction at each zone in closed system

The initial large pressure difference develops the first step boosting with a speedy fluid flow so that air immediately penetrates and pushes steam, and then the diffusion of air into steam volume steadily produced the second step boosting.

2.4 Result of steam boosting in open system

The next simulation is the transient result of steam boosting in open system, as Fig. 5-6. This simulation indicates that the effect of steam boosting is dramatically amplified according to the conditions of outlet and inlet.

Fig. 5-6 shows that the strong release of steam proceeds in a moment of about 0.1-0.2. The dominant boosting is caused from the rapid fluid flow of air.

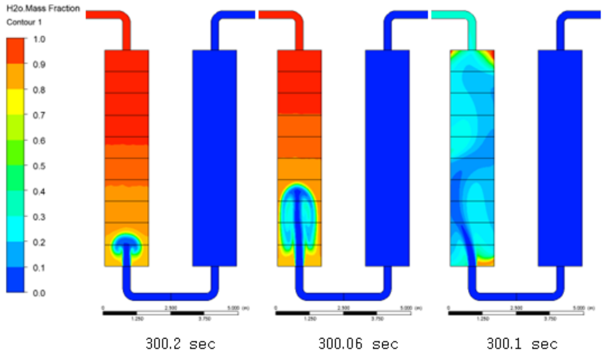

Fig. 5. Steam mass fraction distribution in open system

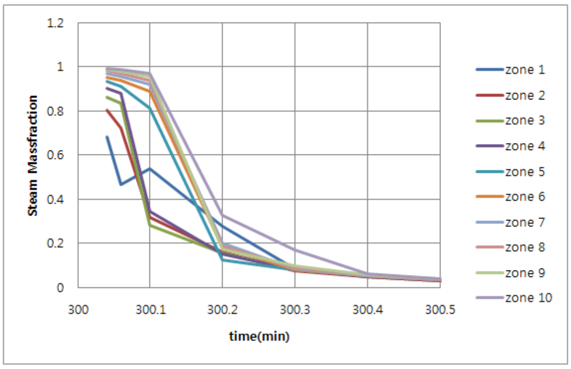

Fig. 6. Steam mass fraction at each zone in open system

3. Conclusions

This paper looks into the simulation of high pressure steam boosting for functional test of nuclear equipment, by utilizing commercial CFD software with two species of steam and air. The simulations are performed to explain steam boosting by solving the fluid fields of steam and air in each closed and open system. The steam boosting is derived from the rapid volume flow and the diffusion.

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