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# Numerical study on hydrodynamic and thermal characteristics of spent fuel pool

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ABSTRACT

In spent fuel pool (SFP), the characteristics of flow and temperature fields incurred by the decay heat from the spent fuel were explored by computational fluid dynamics (CFD) based on Navier-Stokes equations. For decay heat = 0.282–8.466 MW, the numerical results reveal that the height of the maximum fuel-rod temperature ranges between 2.1 and 3.0 m from the bottom of the fuel rod. The larger decay heat causes the location of the maximum fuel-rod temperature to be near the middle of the fuel-rod height. When the decay heat is close to 8.466 MW, the zirconium-water reaction could be incurred by the maximum fuel-rod temperature (>1089 K). To ensure a safe SFP, it is necessary for a nuclear power plant to monitor the fuel-rod temperature in this height range. The research result is a technical reference for evaluation of the thermal effect associated with the spent fuel rods stored in SFP.

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## 1. Introduction

To solve the lack of fossil fuel in Earth, all the countries actively develop the alternative energy. Due to high stability and low cost, the nuclear energy is becoming an important energy supply in lots of countries. However, recent Fukushima Accident (Pavel et al., 2013) shows us that in the developed country the nuclear power plant (NPP) still does not have sufficient and instant ability to handle the damage caused by the natural disaster (e.g. tsunami and earthquake).

Although the nuclear reactor is shut down after disaster, the decay heat of the fuel rods still increases the water temperature in the nuclear reactor. If the cooling systems are out of order, the high fuel-rod temperature will incur the fuel clad made by Zr (see Fig. 1(a)) to execute zirconium-water reaction (ZWR), which generates a large mass of hydrogen in NPP. Finally, NPP is broken by the hydrogen explosions, so the fission products are released to the environment and influence people's health. To prevent damage to NPP, lots of investigations focused on the thermal-hydraulics analysis for NPP under the severe accidents induced by the natural disaster (Shih et al., 2013; Shih and Wang, 2016).

On the other hand, when the fuel rods are not able to maintain the nuclear reaction, the fuel rods must be removed to spent fuel pool (SFP) from the nuclear reactor. It is possible that an increased fuel-rod temperature is incurred by the decay heat. For cooling the spent fuel rods, SFP is full of water and combined with the cooling systems. Concerning SFP filled with water, the studies on the thermal-hydraulics analysis were also investigated by a lot of researchers.

In SFP, the removal of decay heat depends on the strength of the natural convection caused by the fuel rods. Gandhi et al. (2011) indicated that in the regular SFP the strength of the natural convection caused by ten fuel rods is larger than that caused by single fuel rod. Besides, the strength of the natural convection for ten fuel rods is not linearly proportional to that for single fuel rod. Regarding fluid dynamics, the natural convection in SFP is single or two phase turbulent flow (Rowe et al., 1974). Compared to experiments, the numerical study represented that the $k$-$\varepsilon$ turbulent flow model is suitable for researchers to simulate the flow field in SFP (Schröder and Gelbe, 1999). In SFP, a fuel bundle consists of a number of fuel rods (see Fig. 1(b)). To simplify structure, the fuel bundle is replaced with the porous block in the simulation. Hung et al. (2013) revealed that the arrangement of heated porous block has a great influence on the removal of the decay heat.

In term of safety, the simulation showed that ZWR is not incurred by the decay heat generated by the fuel rods placed for 15 years (Ye et al., 2013). In other words, the water natural convection can effectively remove the decay heat generated by the fuel rods placed for 15 years. To avoid ZWR, few researches begin to focus on the probability associated with the removal of decay heat by the air natural convection (Hung et al., 2014). However, the physical model was simplified in previous studies. Here, we establish the three-dimensional fuel bundle model in SFP and numerically explore the characteristics of flow and temperature

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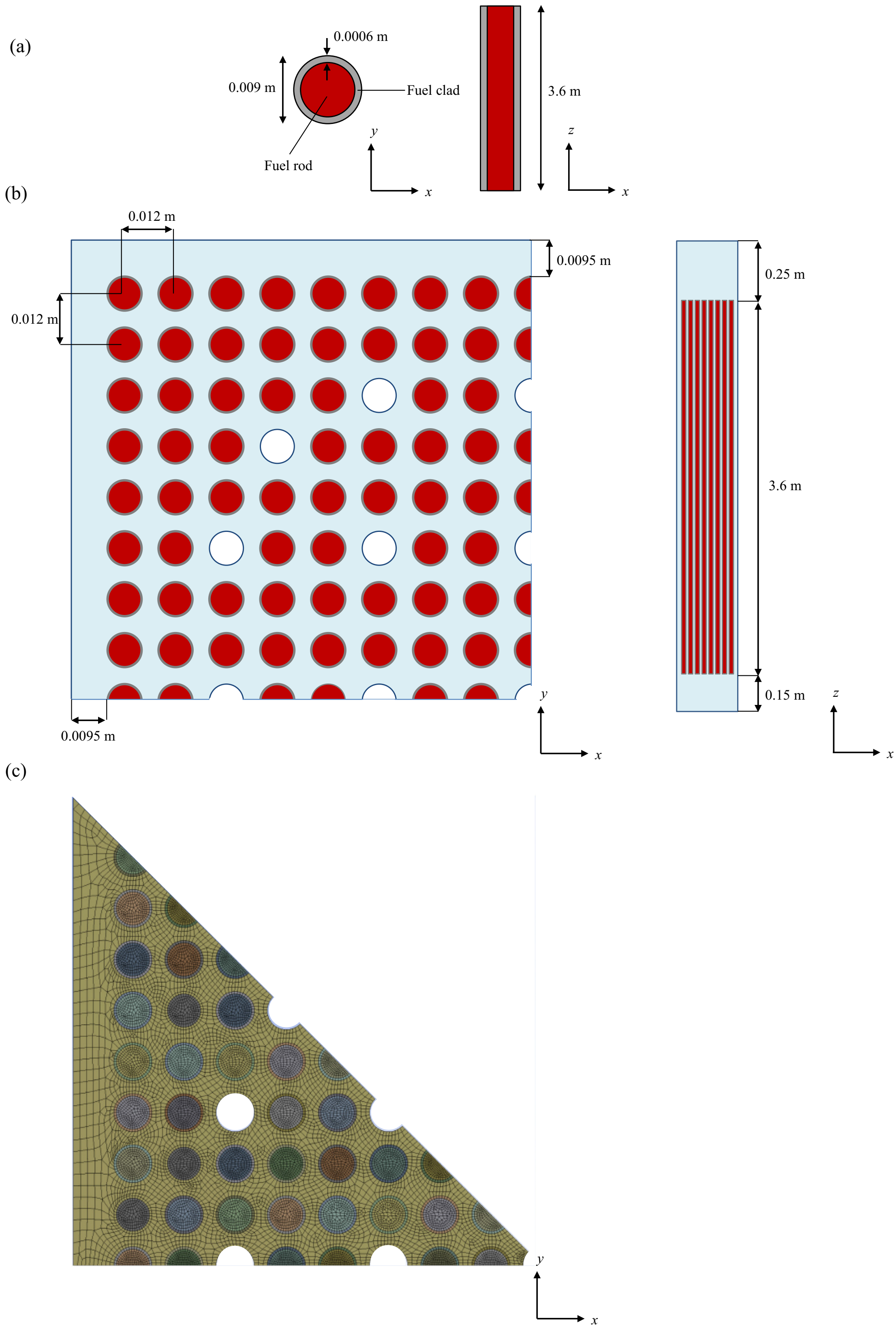


**Fig. 1.** Schematic illustrating the fuel rod (a), quartered fuel bundle (b) and mesh pattern for one-eighth of the fuel bundle in the midplane (c).

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