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Scoping Experiments for Pressure Drop Measurement for the Ex-Vessel Debris Bed Coolability in Severe Accidents

Jin Ho Park [a], Eun Ho Kim [a], Hyun Sun Park [a*], Moo Hwan Kim [b], Weimin Ma [c], Sevostian V. Bechta [c]
[a] *Division of Advanced Nuclear Engineering, POSTECH, Pohang, Gyungbuk, Korea 790-784*
[b] *Korea Institute of Nuclear Safety, Yuseong-gu, Daejeon, Korea 305-338*
[c] *Nuclear Power Safety Division, Royal Institute of Technology (KTH), Stockholm, Sweden*
[*] *Corresponding author: hejsunny@postech.ac.kr*

1. Introduction

In progression of severe accident in nuclear power plants, it is important to assure the coolability of the relocated corium in the reactor cavity due to vessel failure. Because under this circumstance, concrete ablation and over-pressurization caused by molten corium concrete interaction (MCCI) may threaten the integrity of containment, the final barrier of the defense-in-depth, to prevent the release of radioactive material to environment. To ensure the long-term cooling of corium in the reactor cavity, it is important to ensure the coolant ingression into the internally heat generated corium debris bed governed by pressure drop in the porous media.

According to the previous investigations on molten fuel-coolant interactions (FCIs) experiments, the debris beds are expected to form channels in the bed due to intensive boiling and flow. And also, it was found that quenched particulate debris bed was composed of multi-sized (0 ~ 10 mm), irregular shape particles [1, 2] and it has a micro/macro inhomogeneity such as axially and radially stratified debris bed, where a layer of smaller particles covers the main bed part. In this particulate debris bed with the internal heat generation by decay heat, not only co- but also counter-current two-phase flow may be occurred by the water inflow through sides of bed combined with steam outflow to top of bed. For this reason, it is necessary to understand the pressure drop mechanisms in bed with the many conditions which are top-flooding as well as flooding from the other direction to verify the feasibility of water penetration into the particulate debris bed.

2. Model

To predict pressure drop in such heterogeneous debris bed, some empirical and semi-empirical models were developed based on the Ergun equation (Eq. 1) which is the momentum equation to predict the pressure loss of single-phase flow in porous media composed of single sized spherical particles [3].

$$-\frac{dp}{dz}=\frac{150\mu(1-\varepsilon)^2}{\varepsilon^3 {d_p}^2}V_s+\frac{1.75(1-\varepsilon)\rho_f}{\varepsilon^3 d_p}{V_s}^2-\rho_f g \qquad (1)$$

In this equation, the first term means viscous energy loss, second term means kinetic energy loss and last term means the driving force, gravity. In here, 150 and 1.75 are the empirical Ergun constants taken from pressure loss measurements in granular debris and μ and ρ_f are the dynamic viscosity and the density of the fluid respectively, and $-dp/dz$ represents the pressure loss in porous media which has the porosity of ε (Eq. 2) and composed of the spherical particle diameter of d_p when the superficial velocity is V_s.

$$\varepsilon = 1 - \frac{\sum m_p / \rho_p}{V_t} \qquad (2)$$

The parameters K and η called permeability (Eq. 3) and passability (Eq. 4) which mean the measure of the flow conductance and quality of being passable respectively, can be calculated as a function of parameters of debris characteristics (porosity and particle size).

$$K=\frac{\varepsilon^3(d_p)^2}{150(1-\varepsilon)^2} \qquad (3)$$

$$\eta=\frac{\varepsilon^3 d_p}{1.75(1-\varepsilon)} \qquad (4)$$

Based on this Ergun equation, two-approaches have been used in previous researches for considering the effect of irregular shape particles on frictional pressure drop as using shape factor which is defined as the ratio of the surface area of equivalent-volume sphere to that of the actual particle [4, 5] or as modifying the empirical Ergun constants to the other empirical constants for irregular shaped particles [6]. Besides, the obtained effective particle diameter from Ergun equation and measured pressure gradients of single-phase flow in the packed bed have been compared with the averaging mean diameters based on the fraction of mass, area, length, number of particles in each size to consider the effect of particle size distribution [7]. For considering two phase flow in porous media, relative permeabilities and passabilities which are function of void fraction were added to include the influence of the fluid phase on the pressure loss [8, 9, 10].

As mentioned above, many models were developed to judge which mean diameter is suitable for coolability analysis of a heterogeneous debris bed, however, there still exists uncertainties to predict pressure drop in realistic heterogeneous debris bed with the various scenarios.

3. Experimental Facility Setup

To study the effect of each characteristics of heterogeneous debris bed on pressure drop with various conditions, an experimental facility named PICASSO (Pressure drop Investigation and Coolability ASSessment through Observation) facility was constructed.

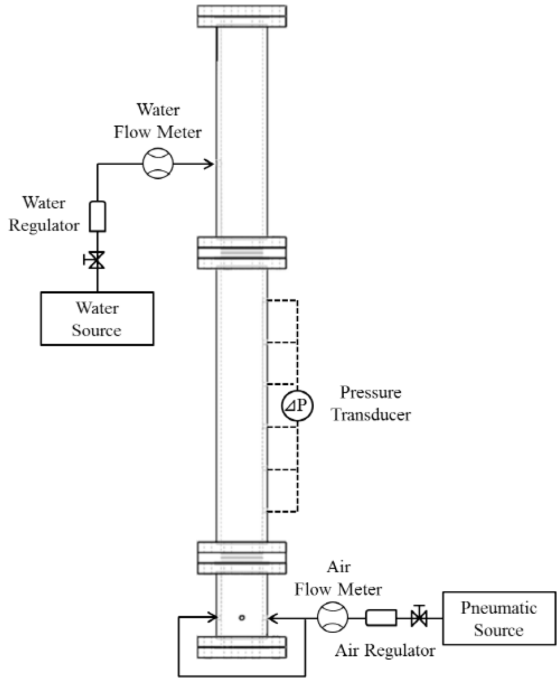

Fig. 1. Schematic diagram of the experimental facility

Fig. 1 shows the schematic diagram of experimental facility. The experimental facility consists of regulators, water and air flow meter, pressure transducer and test section.

The cylindrical test section made by Plexiglas with the inner diameter of 100 mm and the height of 700 mm has 6 holes on the side wall to measure the pressure drop in packed bed. It has a 100 mm difference of level between them.

To hold the particle bed and inject the fluid uniformly in test section, the Plexiglas meshes which have holes with the diameter of 2 mm and the pitch of 3 mm locate in top and bottom of test section, and there are two cylindrical Plexiglas tubes to supply the water into the top of test section and to inject water or air into the bottom of test section respectively.

4. Scoping Test and Result

With the experimental facility, the single phase flow experiment using air was performed to check the reliability of the test condition using SUJ-2 balls (density: 7,860 kg/m^3) with the diameter of 2 mm, 5 mm respectively (Table I), and the experimental data compared with Ergun equation.

Table I: Scoping test case

Particle Size (mm)	Shape	Porosity
2	Sphere	0.383
5	Sphere	0.394

Before conducting the experiment, all of measurement devices were calibrated. Air flow rate was measured by PFM5 Series manufactured by SMC Korea with the range of 2 ~ 100 LPM and its accuracy of ±3% and pressure drop was measured by Model 230 manufactured by SETRA with the range of 0–2 PSID and the accuracy of ±0.25%. Valve manifolds were used to equalize pressure between high and low pressure ports.

At the beginning of the test, the total mass of particles was measured and porosity was obtained. Secondly, upward air flow was injected at the bottom of test section in ambient condition. Thirdly, the air flow rate and the pressure drop were measured when steady-state condition was established. Finally, the air flow rate was increased to another value, and immediately above step was repeated.

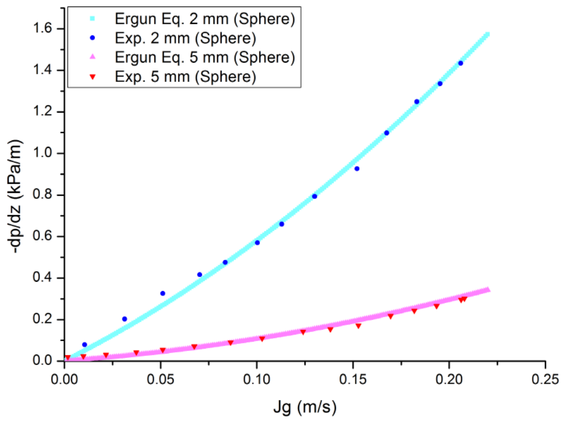

Fig. 2. Comparisons of the experimental data (2 mm and 5 mm spherical particles) with Ergun equation

Fig. 2 shows a result of the single phase flow experiment using air, Ergun equation predicts the experimental data well with a mean deviation of 14.62 %.

5. Conclusions

To investigate the effect of each characteristics of heterogeneous debris bed expected in real severe accident scenarios on pressure drop with various conditions, an experimental facility called as PICASSO (Pressure drop Investigation and Coolability ASSessment through Observation) facility was constructed. With the experimental facility, the scoping test was conducted as injecting upward air flow into the bottom of particle bed composed of 2 mm, 5 mm spherical SUJ-2 balls respectively, and the experimental data compared with Ergun equation. As a result of the single phase flow experiment using air, Ergun equation predicts the experimental data for the spherical particles with the diameter of 2 mm and 5 mm with a mean deviation of 14.62 %.

6. Future Work

As a result of intensive previous researches, many issues in severe accident have been resolved. However, some uncertainties to predict the pressure drop in heterogeneous bed are still remained. In the cases of irregular particle shape, many models were suggested as adopting shape factor or modifying the Ergun constants. However, there exist uncertainties in terms of description of particle shape and well-prediction in whole range of superficial velocity. Therefore, it is needed to adequately describe the effects of particle shape on flow paths affecting to hydrodynamic resistance.

For these reasons, test case (Table II) is selected to investigate on the effect of particle shape on frictional pressure drop in particle bed. The diameters (D) and lengths (L) of non-spherical particles are deduced to have the same mean diameters (Sauter mean diameter, d_{sd} and Equivalent diameter, d_{eq}) with spherical particle size.

Table II: Test case using water as a working fluid

Bed	Shape	Particle Size (mm)		Shape Factor	d_{sd} (mm)	d_{eq} (mm)
		D	L			
1	Sphere	2	-	1	2	2
2	Cylinder	1.98	2.04	0.873	2	1.75
3	Cylinder	1.98	4.95	0.805	2.48	2
4	Sphere	5	-	1	5	5
5	Cylinder	4.98	5.04	0.874	5	4.37
6	Cylinder	4.98	13.9	0.789	6.34	5

7. Acknowledge

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