Numerical Analysis of the Pressure Drop on a Flow Channel Filled with Catalysts for Nuclear Hydrogen Production System

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1. Introduction

Designing a process heat exchanger (PHE) is one of the main technical challenges in the development of a nuclear hydrogen production system. The PHE provides an interface between the helium gas and the sulfuric acid gas. The SO3 gas is heated and decomposed into SO2 and O2 in the PHE. For this reason, PHE is also called a sulfur trioxide decomposer. The Korea Atomic Energy Research Institute (KAERI) has developed a hybrid-design decomposer to withstand severe operating conditions. Figure 1 shows the layout of the PHE which has a hybrid form of its flow channel geometry; there is a printed-circuit form on the primary helium side and a plate-fin form on the secondary SO3 side [1]. The SO3 flow channels have enough space to be filled up with 1-4mm diameter catalysts which are shown in Fig. 1. There are many widespread correlations for the porous media such as the Carman, Ergun, Zhavoronkov et al., Susskind & Becker and Reichelt correlation [2]. In the nuclear field, the KTA correlation was developed for a reactor core design for a high-temperature gas-cooled reactor [3].

In this paper, we discussed a numerical analysis and validation of a pressure drop on a SO3 flow channel filled with various sized catalysts.

2. Pressure Drop Analysis

2.1 Empirical Correlation

In the case of porous media filled with pebble (or catalyst), the pressure drop can be defined as follows;

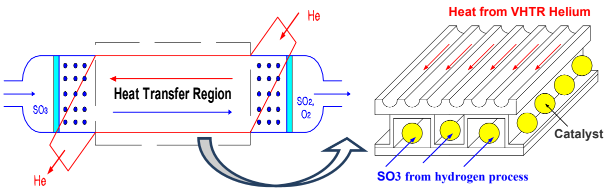
$$\Delta p = \varphi \frac{L}{d_p} \frac{\rho V^2}{2} \left(\frac{1-\varepsilon}{\varepsilon}\right), \qquad (1)$$

where ε is the porosity (void fraction) in the bed defined as,

$$\varepsilon = \frac{V_{void}}{V_{bed}} . \qquad (2)$$

The hydraulic diameter (d_h) of the system depends on the void fraction and pebble diameter(d_p),

$$d_h = d_p \left(\frac{\varepsilon}{1-\varepsilon}\right) . \qquad (3)$$



(a) Heat Exchanger (b) Flow Channel

Fig. 1. Hybrid Type Process Heat Exchanger

The pressure loss coefficient φ obtains from one of the empirical correlations listed in Table I.

2.2 Numerical Modeling

Two-dimensional unstructured grids are produced for a flow channel (600mm [L] x 4.5mm [H]) filled up with 200 3mm ball-shaped catalysts as shown in Fig. 2. To avoid the generation of poor quality mesh cells from every contact points between catalysts, we assumed that all catalysts are line-up evenly in the middle of the flow channel with a 2% reduction in size compared to the original size. The major information of the computational model is as follows,

1. A total of 1,559,754 nodes is generated for numerical simulation
2. Nitrogen gas is used as a fluid medium instead of SO3 gas and defined to be incompressible
3. The flow regime covers a laminar flow
4. A standard wall function is used with a smooth wall option

The model was implemented in a commercial *computational fluid dynamic* package, a CFX-13.0 [4].

Table I: Characteristics of Empirical Correlations.

Correlation	Packing shape	Wall effect	Inertia effect
Carman	Regular	No	No
Susskind & Becker	Regular	No	Yes
KTA	Regular	No	Yes
Ergun	Irregular	No	Yes
Zhavoronkov et al.	Irregular	Yes	Yes
Reichelt	Irregular	Yes	Yes

Fig. 2. Two-dimensional meshes for numerical analysis

3. Results and Discussion

The pressure drop simulation is compared with the well-known correlations (Fig. 3). The major characteristics of the correlations are listed in Table I. The present loss coefficients are determined from the pressure drop obtained by the numerical model as,

$$\varphi = \frac{\Delta P}{L}\frac{d_p}{\rho V^2}. \qquad (4)$$

The simulation results show that a regular packing configuration agrees better with the correlations from Carman, Susskind & Becker and KTA than those with irregular packing. The channeling effect in regular packing enables gas to flow smoothly throughout the entire bed. This induces a lower pressure drop than those of irregular packing at the point of the same average void fraction. Meanwhile, the correlations from Ergun, Zhavoronkov et al. and Reichelt for irregular packing estimate higher pressure drops than those of regular packing. The irregular packing configuration is closer to the actual catalyst bed. Thus, the bed irregularities should be taken into account for a correct pressure drop description.

The comparison results show that the validity of the numerical analysis is not satisfactory when using the existing correlations. The main reason for this may be due to a discord of the channel geometry and an extreme irregularity in the size of the catalyst. It should be accomplished by comparing its result with the experimental data. We prepared an experimental apparatus for a pressure drop validation (Fig. 4). The test section simulates a single channel of the PHE secondary side plate-fin channel and will be filled up with regular sized catalysts from 1mm to 4mm in diameter.

4. Conclusions

We discussed a numerical analysis and validation of a pressure drop on a flow channel filled with catalysts in the channel. The results of the pressure drop simulation are compared with the results obtained using well-known empirical correlations. From the comparison results, the validity of the two-dimensional numerical analysis is not shown. The main reason may be due to a discord of the channel geometry and the extreme irregularity in the size of the catalyst. It should be accomplished by comparing its results with the experimental data, yet there are no experimental data available up to now.

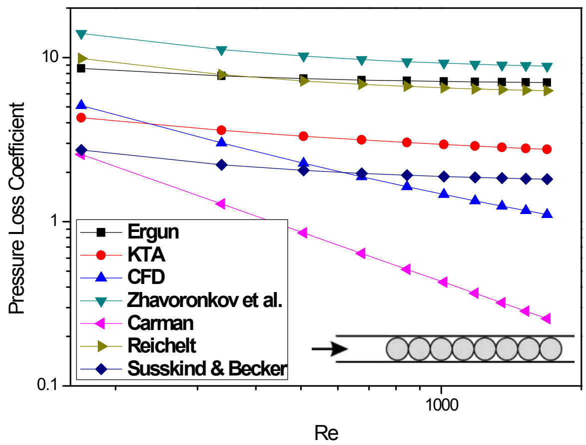


Fig. 3. Loss coefficients for a catalyst channel.

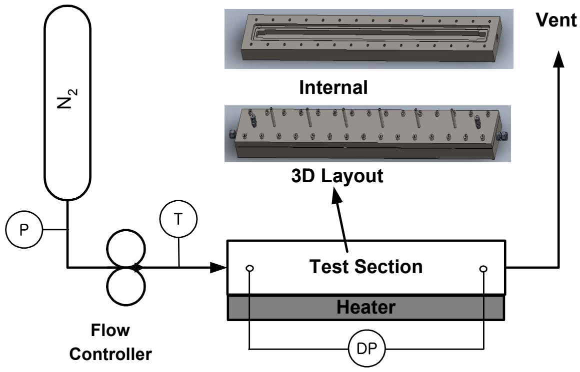


Fig. 4. Experimental setup for validation.

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