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Analysis on Flow Pressure in the Pneumatic Braking System of FHS-RDE Using Fluent 6.3 Software

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A B S T R A C T

The High Temperature Gas Cooled Reactor (HTGR) is considered as one of the nuclear reactors of generation-IV type in the future. The fuel handling system is one of the important processes in HTGR as well as in the design of Reaktor Daya Eksperimental (RDE). In the Fuel Handling System (FHS), the fuel pebble is transferred pneumatically along the pipe using carrier gas into the core of the reactor. Therefore, the pneumatic is an important system in operation stability of FHS. During the developing process of FHS-RDE, a branch pipe as a braking pipe system is provided on top of the pneumatic system to reduce the speed of the fuel discharged from the pneumatic pipe. The pneumatic pipe has an inner diameter of 65 mm and 20 m in length, whereas a branch pipe diameter for the braking system is 30 mm. The pneumatic system pressure is greater than the reactor cooling system pressure of 3.0 MPa. This work was performed to investigate the pressure drop and flow pattern of the braking system of FHS by various carrier gas inlet pressure. The analysis was carried out by Fluent 6.3 Software. Based on the design parameter of FHS used in the analysis, the results show that the performance of the braking system is not significant to reduce the pressure in the top region of the pneumatic pipe. To obtaining a significant reduction in pressure, and evaluation on the design of the branch pipe as well as the radius of curvature of the bend at the top pipe is suggested.

1. INTRODUCTION

The High Temperature Gas Cooled Reactor (HTGR) is considered a type of nuclear reactor power plant for the future in the world which has attractive inherent safety features and high efficiency [1]. This nuclear reactor has been developed in many countries with various power capacities especially as Small Modular Reactors (SMRs) to produce the heat application as well as to generate electricity. The HTGR type reactor with the thermal power of 10 MW as SMR has been successfully operated in China [2]. A small size reactor called Reaktor Daya Eksperimental (RDE) has been also designed by Batan that have a thermal power of 10 MW [3, 4]. Its design was adopted from the Generation-IV HTGR technology similar to that operated in China.

The reactor core contains the spherical shape of fuel pebbles in which the primary cooling system of the reactor uses the helium gas. In the Fuel Handling System (FHS) of the reactor, the fuel pebble is transferred pneumatically using carrier gas to transport into the reactor core. The pneumatic is a system that contains or uses

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pressurized gases such as helium gas to create a mechanical response through an enclosed pipeline.

In normal operation of HTGR, the fuel pebble of the reactor can be loaded, discharged, and reloaded continuously in which without operating the reactor shut down [5]. The new fuel pebble is lifted through a pipe and pebble counter perpendicularly into the pneumatic pipe by helium gas to the reactor core and discharged from the reactor core by gravities. The diameter of the sphere (fuel pebble) is close to the internal pipe diameter of the pneumatic systems. So, the pneumatic transfer system for fuel pebble is the main role important in obtaining the stability of the fuel handling operation.

In the operation of HTGR, several parameters of FHS that relating to the pneumatic systems are highly necessary. Therefore, the performance of the FHS is one of the important aspects of the operation of HTGR.

In the FHS design of RDE, a high temperature helium gas from the primary cooling loop is used as a carrier gas. To maintain the material integrity of the pneumatic system and efficient compression system, the carrier gas is kept at the temperature of about 60 ^{o}C. To reduce the speed of the fuel coming out of the pneumatic pipe, an additional branch pipe as the braking system is placed on top of the pneumatic pipe system. In principle, this system is a branch pipe so that some of the flow goes to the branch pipe. Meanwhile, the effect of flow braking on the pressure decrease on top of pneumatic pipe can be analyzed by Fluent 6.3 Software. The Computational Fluid Dynamic (CFD) Fluent is very commonly used in investigating the flow patterns in pipes for industrial processes [6, 7].

Based on the description above, the purpose of this analysis is to investigate the pressure drop and flow pattern to evaluate the performance of the braking system of FHS by various carrier gas inlet pressure. It is carried out to obtain the effect of flow braking caused by pressure decreasing on the top region of the pneumatic pipe of RDE.

2. FUEL HANDLING SYSTEMS (FHS)

In the design of FHS, the main priority of safe condition are optimal and reliable operations. So that fuel pebbles can be loaded into the reactor core, circulated and their burn-ups are detected perfectly. The FHS is one of the important systems with supporting equipment including the system of charging and discharging control, fuel separator system, a pneumatic system of fuel loading, fuel counter, and burn-up measurement. Figure 1 shows the diagram of FHS schematically which consists of the pneumatic component (loading system) and discharged facilities. These processes are carried out continuously operating automatically. In the process of the pneumatic system, the fuel pebbles are lifted using a helium gas compressed as the carrier medium from the bottom to the reactor core. The pneumatic system pressure is bigger than the reactor cooling system pressure of 3.0 MPa. In the design of pneumatic FHS, the carrier gas mass flow rate is approximate 3.0 kg/s that taken from the primary coolant system of the reactor.

During developing process of FHS-RDE, a braking pipe system is provided on top of the pneumatic system. The pneumatic pipe has an inner diameter of 65 mm and length is approximately 20 m [8]. A branch pipe for the braking pipe is 30 mm diameter located on top of the pneumatic pipe.

The carrier gas is blown to the region of the suction side of the primary cooling blower. From the primary cooling loop of the blower, the carrier gas pressure is increased by the pneumatic compressor after going through the cooler as shown as schematically diagram in Fig. 1. The arrows indicate the direction of the fuel path in operation of FHS.

Furthermore, the helium gas passes and fills up to the vessel at the start of the pneumatic line. Arriving fuel pebbles are carried along by the flow of carrier gas from there. At the end of the carrier pipe, the gas flows back to the reactor vessel. Meanwhile, a part of the gas flow that goes to the braking pipe will be returned to the primary loop system. This gas flow plays a role in reducing the pressure at the pneumatic pipe outlet which throws the fuel pebble to the reactor core so as to reduce the impact between the fuel pebble and the surface of the reactor core.

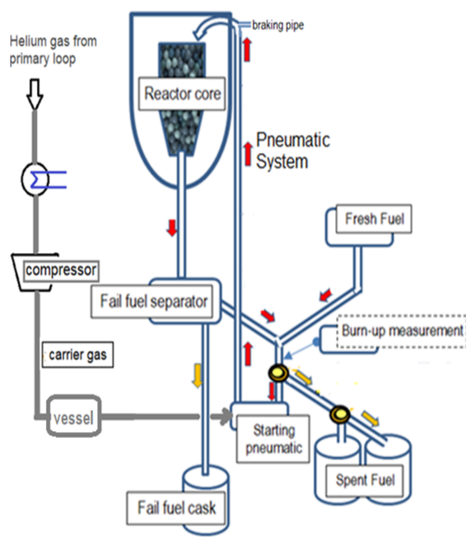

Fig. 1. Schematically Diagram of FHS Design [5]

3. METHODOLOGY

An analysis of the braking system is conducted using the Fluent 6.3 Software. It is a software of computational fluid dynamics (CFD) to simulate the fluid flow problems. Geometry and grid generation is done using Gambit Code. The governing equations of pipe flow are derived from the principle of mass, momentum, and energy conservations. It is derived from the Navies-Stokes equations and provides a complete mathematical description of the flow motion.

The CFD software of Fluent 6.3 is used to obtain a clear view. In this analysis, the observation is focused on the fluid dynamics in case of the pressure gradient through a pneumatic pipe. In this modeling, it does not involve the heat source at the pipe surface. The pipe branch of the braking system in the pneumatic system is shown in Fig. 2.

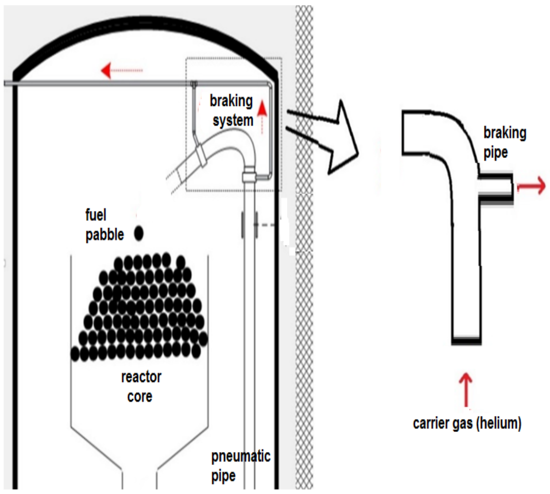

Fig. 2. Diagram of the braking system [9]

The followings below are parameter data and condition considered in the analysis,

- fluids are helium as a carrier gas and pipe materials are stainless steel.
- the flow of carrier gas is stable along the pipe.
- the pneumatic system pressure is bigger than the reactor cooling system pressure of 3.0 MPa.
- the temperature of carrier gas is approximately 60 ^oC.
- there is no heat source along the pipe.
- a model of 1 m length and 0.65 m diameter are drawn.
- the generated mesh is considered suitable for this model.
- mass flow rate, pipe material, carrier gas properties are set accordingly.
- the calculation starts with the beginning of iteration which then convergences at a point.

4. RESULTS AND DISCUSSION

A model was implemented in the Fluent to specifically observe the pressure phenomena, in particular, the decreasing pressure near the top of pneumatic pipes. The simulation was conducted in terms of the single-phase flow of helium gas and convergence calculation in less than 1000 iterations. Figures 3 to 6 show the pressure contour through the top of the pipe at the inlet pressure from 3.05 MPa to 3.15 MPa. At an inlet pressure of 3.05 MPa shows that the pressure drop is only 0.002 MPa, then the pressure drop increases at the inlet pressure of 3.09 MPa, 3.12 MPa, 3.15 MPa, respectively of 0.003 MPa, 0.005 MPa, and 0.008 MPa. In general, as the flow enters the bend curvature, the flow profile becomes irregular. It's as shown in the pictures, the flow patterns of back mixing occur at inner bends. This is a normal condition as it occurs in the flow pressure contour in the manifold pipe, elbow, and pipe bends [10–12].

The pneumatic system pressure is bigger than the reactor cooling system pressure of 3.0 MPa. Furthermore, based on this analysis which it uses various inlet pressures, so obtained the pressure decrease in the top region of pipe. The result shows that the pressure decrease is maximum at around 0.008 MPa at the pneumatic inlet pressure of 3.15 MPa. Meanwhile, in the case of 3.05 MPa inlet pressure, the pressure drop is only 0.002 MPa. This means that the higher flow inlet pressure, the bigger pressure decreasing is at the outlet pipe. Figure 7 shows the trend curves, which shows the pressure drop as a function of the inlet pressure.

The purpose of the braking system is to reduce the loading speed of the fuel pebble to the reactor core. Therefore it's expected that the collision of fuel loaded into the core will be reduced. Therefore the integrity of fuel loaded into the core can be maintained. However, if it's compared to the existing operating system pressure, this outlet pressure decreasing in the top pipe is not significant. Total pressure contour illustrates that the decreasing pressure is relatively low concerning that observed on the inlet flow pressure of carrier gas. While the inlet pressure depends on the performance of the pneumatic system to maintain the fuel pebble lift reaching the outlet pipe, under normal or abnormal operating conditions.

As a discussion, the pressure drop can be influenced by the diameter of the branch pipe for the braking system as well as the inlet pressure of the pneumatic system. Besides that, to obtain a reduction in pressure, the radius of curvature of the bend at the top also should be further considered. Furthermore, as a consideration, the suction system with a certain flow pressure connected to the braking pipe can reduce the flow pressure on the pneumatic top pipes.

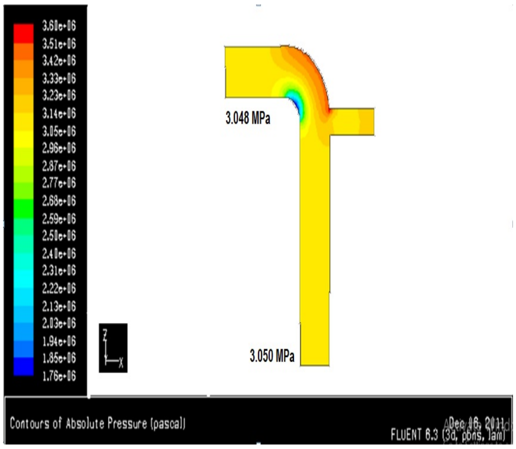

Fig. 3. Pressure contour at the inlet pressure of 3.050 MPa

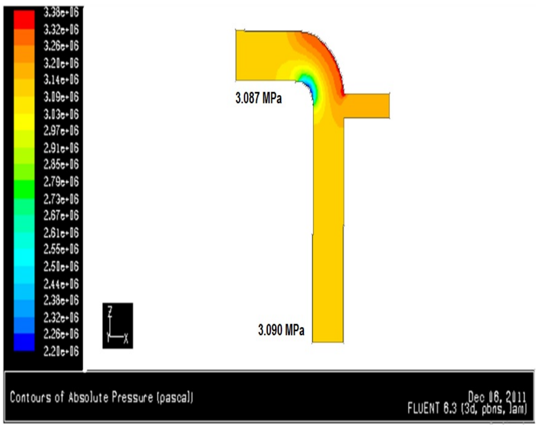

Fig. 4. Pressure contour at the inlet pressure of 3.090 MPa

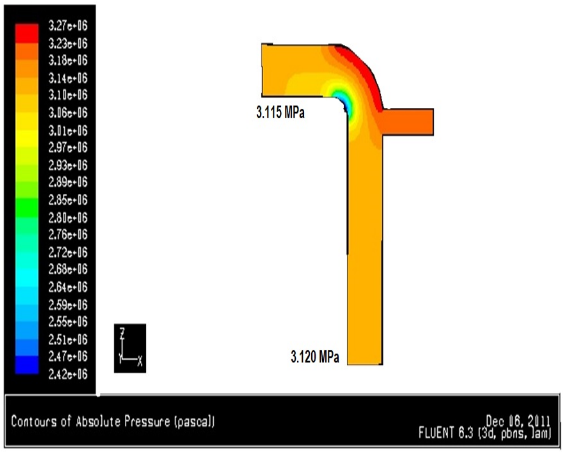

Fig. 5. Pressure contour at inlet the pressure of 3.120 MPa

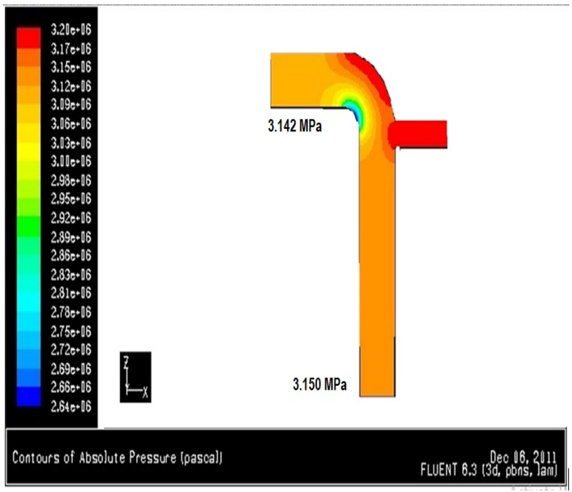

Fig. 6. Pressure contour at the inlet pressure of 3.150 MPa

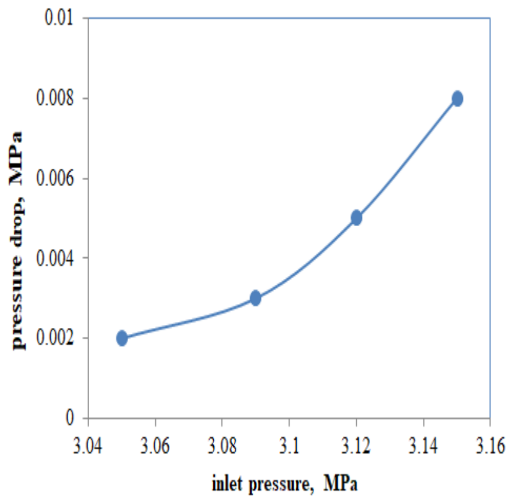

Fig. 7. The curve of inlet pressure vs. Pressure drop in outlet Pipe

5. CONCLUSION

Based on computational fluid dynamics analysis using FLUENT 6.3, the simulation in the braking system of the pneumatic pipe of FHS was carried out successfully, which was an effective and feasible method of analysis. The results of simulations show that the pressure drop and the flow pattern have been identified. Based on the calculation of pressure drops the performance of the braking system is not significant to reduce the pressure in the top region of the pneumatic pipe. To obtain a significant reduction of the pressure, further, an evaluation of the design of the branch pipe as well as the radius of curvature of the bend at the top pipe is suggested.

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