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A deceleration system for near-diameter spheres in pipeline transportation in a pebble bed reactor based on the resistance of a pneumatic cushion

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HIGHLIGHTS

- A deceleration system for fuel transportation in a pebble bed reactor is designed.
- Dynamic analysis and motion analysis of the deceleration process are conducted.
- The effectiveness of the system is verified by the analysis and the experiment.
- Some key design parameters are studied to achieve effective deceleration.
- This research provides a guide for the design of a pebble bed reactor.

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ABSTRACT

The fuel elements cycle occurring inside and outside the core of a pebble bed reactor is carried out by pneumatic conveying. In some processes of conveyance, it is necessary to reduce the velocity of the moving fuel element in a short time to avoid damage to the fuel elements and the equipment. In this research, a deceleration system for near-diameter spheres in pipeline transportation based on the resistance of a pneumatic cushion is designed to achieve an effective and reliable deceleration process. Dynamic analysis and motion analysis of the deceleration process are conducted. The results show that when the fuel element is moving in the deceleration pipeline, the gas in the pipeline is compressed to create a pneumatic cushion which resists the movement of the fuel element. In this way, the velocity of the fuel element is decreased to below the target value. During this process, the deceleration is steady and reliable. On this basis some key design parameters are studied, such as the deceleration pipeline length, the ratio of the diameter of the fuel element to the internal diameter of the pipeline, etc. The experimental results are generally consistent with the analysis and demonstrate the considerable effectiveness of the deceleration process as well. This research provides a guide for the design of the fuel elements cycling system in a pebble bed reactor along with the optimization of its control.

1. Introduction

The modular pebble bed high temperature gas-cooled reactor is considered to be a preferred candidate for the fourth generation nuclear power system because of its advantages such as inherent safety and high efficiency (Zuoyi et al., 2009; Fertel, 2011). Therefore its development attracts more and more attention (Zongxin and Zuoyi, 2000; Sabharwall et al., 2013; Abram and Ion, 2008). Fuel elements are loaded and discharged continuously in a pebble bed reactor: thousands of fuel elements are discharged from the core every day; the fuel elements which have not reached the target burnup are lifted to return to the core; those which have reached the target burnup are conveyed to the spent fuel elements storage system; some new fuel elements are loaded into the core at the same time (Kai et al., 2011; Jiguo et al., 1996). Fuel elements are conveyed by pneumatic conveying in hundreds of meters of pipeline outside the core (Lin et al., 2009; Jiguo et al., 2001). The

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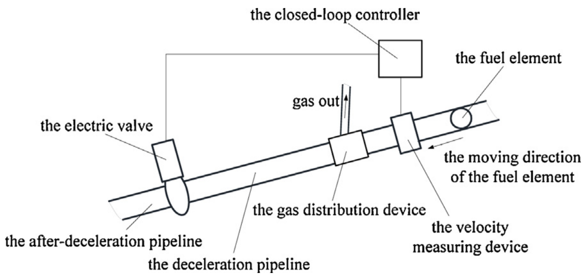

Fig. 1. Composition of the deceleration system.

diameter of the fuel element is very close to the internal diameter of the pipeline with the ratio ranges from 0.92 to 0.97. This is called near-diameter spheres in pipeline transportation (Peng et al., 2012a,b). It is necessary to reduce the velocity of the moving fuel element in a short time in some processes of conveyance, such as the fuel element getting into the core or the bend, so that the damage to the fuel elements and the equipment caused by the collision can be avoided (Jiguo and Hongling, 2001).

Curtolo et al. (2003) designed a device for slowing down spherical elements in a pebble bed reactor. The device injects some gas into the pipeline to form a gas flow of which the moving direction is opposite to that of the fuel element. Thus the velocity of the fuel element is reduced by the gas flow. Kai et al. (2010) offered a method and system for decelerating pneumatic delivery of pebble bed reactor fuel elements. The system consists of a device for detecting the speed of the ball at the entrance, a front end gas shunt, a middle end gas shunt, a decelerating elbow pipe, a device for detecting the velocity of the ball at the exit, two regulating valves and two flow meters. The velocity of the fuel element is reduced because of the drop of the pneumatic thrust. The friction between the fuel element and the elbow pipe contributes to the deceleration as well. What is more important, the system achieved the adjustability of the deceleration process. However, these devices or systems are complex in structure. This makes the construction very difficult. They consist of so many devices that the control design is a big problem. Besides, the system takes up too much room, such as the elbow pipe. Therefore, it is of great significance to design a reliable and simple deceleration system.

This paper introduces a deceleration system for near-diameter spheres in pipeline transportation in a pebble bed reactor based on the resistance of a pneumatic cushion. The dynamic analysis of the deceleration process is conducted and the motion characteristics are analyzed in addition. Some key design parameters are studied to achieve effective deceleration. The experiment is made on the deceleration system experiment platform. The experimental results prove the calculation results. A conclusion is obtained that the velocity of the moving fuel element is decreased effectively by the resistance of the pneumatic cushion. Great effectiveness and reliability of the deceleration can be achieved in various conditions with this system.

2. Composition and principle of the deceleration system

2.1. Composing of the deceleration system

The system consists of a deceleration pipeline, a velocity measuring device, a gas distribution device, an electric valve and a closed-loop controller, as shown in Fig. 1. The velocity measuring device is installed before the deceleration pipeline. The gas distribution device and the electric valve are installed on the deceleration pipeline successively along the moving direction of the fuel element. The gas distribution device is installed at the entrance of the deceleration pipeline. The electric valve is installed at the exit of

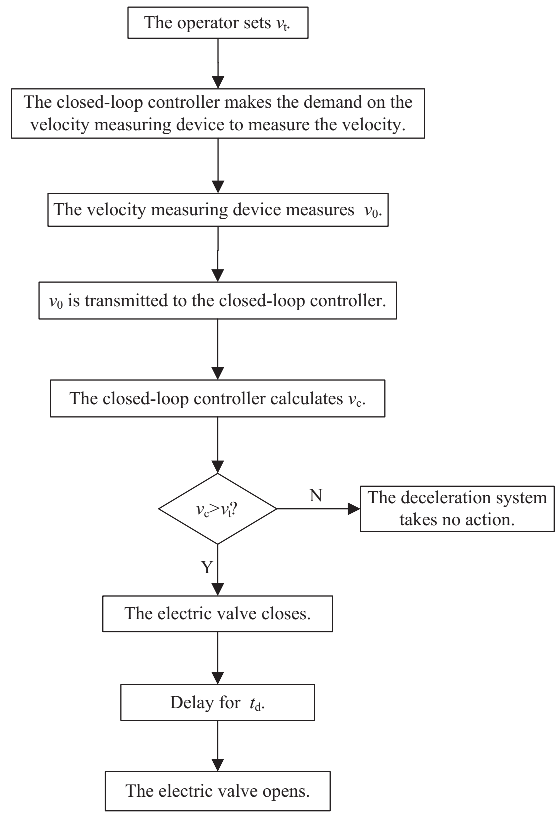

Fig. 2. Principle of the deceleration system.

the deceleration pipeline and connects with the after-deceleration pipeline.

The deceleration pipeline can be installed in any direction, such as horizontal, vertical and tilt. The velocity measuring device is a non-contact electromagnetic device. It can measure the velocity of the fuel element passing by. The electric valve has two states. When it is open, the fuel elements can get to the after-deceleration pipeline through it; when it is closed, the deceleration pipeline and the after-deceleration pipeline are separated and thus the fuel elements and the gas cannot get through the valve.

2.2. Principle of the deceleration system

The principle of the deceleration system is shown in Fig. 2. The electric valve is open in the initial state. The operator sets the target velocity of the fuel element after deceleration, namely v_t. When the closed-loop controller makes the demand on the velocity measuring device to measure the velocity, the velocity measuring device measures the velocity of the fuel element. Then the velocity data is transmitted to the closed-loop controller as the initial velocity v_0. The closed-loop controller calculates v_c, which represents the velocity of the fuel element when it reaches the exit of the deceleration pipeline without deceleration. If $v_c \le v_t$, the deceleration system takes no action and the fuel element gets to the after-deceleration pipeline directly; if $v_c > v_t$, the valve closes and last for a time period t_d which is calculated by the closed-loop controller.

3. Dynamic analysis of the deceleration process

The force condition and the motion of the fuel element are shown in Fig. 3. As the fuel element moves forward, it makes constant collisions with the pipeline. When the electric valve is closed, the fuel element is subjected to many forces, including gravity mg, the resistance of the gas F_g, the support of the pipeline F_N and the