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Impact of bogie cavity shapes and operational environment on snow accumulating on the bogies of high-speed trains

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A R T I C L E I N F O

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A B S T R A C T

In this paper, the snow accumulation on the bogies of high-speed trains has been investigated using a numerical simulation method based on the unsteady Reynolds-Averaged Navier-Stokes simulations (URANS) coupled with the Discrete Phase Model (DPM). The effects of bogie cut outs' shape, running speed of high-speed trains and snow particle density and diameter on the snow accumulation and particle movement characteristics are discussed. The results show that the bogie installation region with inclined plates shows better anti-snow performance than the configuration with straight plates, which greatly affects the flow structure and snow concentration distribution in the upper space of bogie regions. The running speed of high-speed trains has dominant effect on the snow accumulation on the bogies, and the snow accumulation issue of bogie becomes more serious with increasing running speed. Furthermore, the snow particle density and diameter also have large influence on the snow accumulation on the bogies. With the increase of snow particle density and diameter, the flow range at height direction around bogie region of snow particles become lower and the quality of snow accumulation decrease significantly.

1. Introduction

With the rapid development of high-speed trains around the world, a large number of high-speed train operation has been developed incrementally in cold and snowy areas, such as the Beijing-Harbin High-speed Railway, Harbin-Dalian Passenger Dedicated Line in Northeast of China, the Lanzhou-Xinjiang Second Railway in Northwest of China, the Tohoku Shinkansen and Tokaido Shinkansen in Japan and Bergen Railway in Norway etc. The bogies of high-speed trains have been damaged by snow while running at high speed in snowy weather (Allain et al., 2014), as shown in Fig. 1. The snow and ice accumulating on the bogies would cause series of problems. For example, snow and ice packing on the elastic suspension restrains the displacement of springs which seriously intensify the vibration of the train (Giappino et al., 2016). The heat radiated by the motors and gear covers of high-speed trains will melt the snow particles into liquid water which can transform into heavy ice at lower temperature, resulting in the axle load increase (Cao et al., 2016). Snow and ice accumulating on the levelling valve of vehicles will have great effects on the vehicle dynamic performance during curve negotiation. Especially, the moving parts of brake calipers may be hindered by the ice, which results in being a more dangerous operation of high-speed trains (Kosinski and Hoffmann, 2007). Thus, it is necessary to have a deeper study on the snow accumulation on the bogies to ensure the operational safety of high-speed trains and improve the comfort of passengers.

To solve this issue, a large number of studies have been undertaken in the past decades. Some European railway institutions have investigated the methods to remove the snow and ice covering on the bogies. Scotland railway institution used hot air to melt the ice on the equipment of the bogie (Scott, 2010). In Sweden, the environmental propylene glycol was heated circularly to eliminate the snow and ice (Maxime, 2011). Finland railway institution thawed the ice by spraying the hot water above the bogie (Bettez, M., 2011). A propylene aqueous solution was adopted for removing the ice on the bogie in Russia (Paulukuhn, 2012). Moreover,

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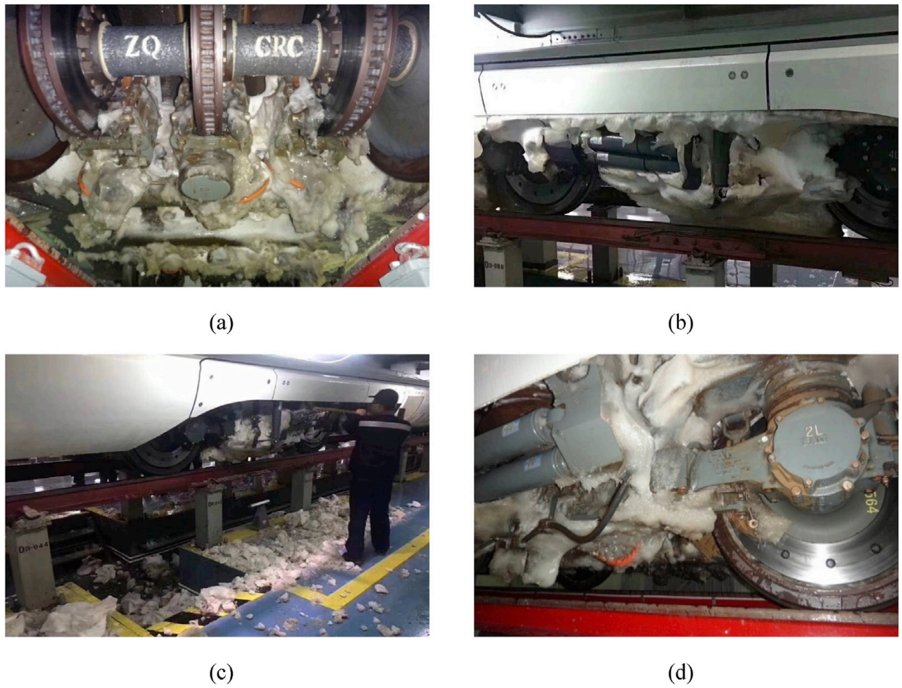

Fig. 1. Snow and ice accumulation on the bogies of high-speed trains.

some other countries alleviated the snow and icing problem of bogies by reducing the amount of snow accumulating on the railway lines. For instance, new viaducts were built on the Tohoku Shinkansen Line to mitigate the ice problem of the bogie (Fujii et al., 2002). The spraying devices were installed beside the Tokaido Shinkansen Line to reduce the amount of snow accumulation on the railway (Thomas, 2009). The Sweden railway institution used the snowbrushes to prevent the snow particles accumulating beside lines to be rolled into the track. To prevent massive snow particles flowing into the track, the snow fences were built along the Bergen Railway (Bettez, 2011). However, the de-icing and snow removal devices mentioned above are fixed at certain locations to deal with the ice and snow problems. In addition, the methods about how to prevent the issue of snow and ice accumulating on the bogies are rarely mentioned in literature. Furthermore, China has the longest operating high-speed railway lines in the northern vast cold areas where the high-speed trains travel during long time (several hours at a time). Therefore, the snow-accumulating problem of bogies, imposing a threat to the safety of high-speed trains, is important physical phenomena for the China High-speed Rail which requires an urgent solution.

During snowy weather, the snow flowing into the bogie installation region due to the slipstream induced by the motion of high-speed trains (Paulukuhn, 2012) is a typical snow-drifting phenomenon, and can be simulated using a wind-snow two phase flow method (Okaze et al., 2011; Smedley et al., 1993; Uematsu et al., 2010; Beyers and Waechter, 2008; Tsuchiya et al., 2002). From the point of view of computational fluid dynamics simulations, the Euler-Euler (E-E) and Euler-Lagrange (E-L) methods are generally accepted as the most suitable to evaluate two-phase flow problem. Euler-Euler (E-E) model treats both phases as continuous flows interpenetrating each other, while Euler-Lagrange (E-L) model solves the fluid flow using Navier-Stocks equations and the particles are injected into the flow and are then tracked individually to calculate their trajectories inside the gas (Valentine and Decker, 1995).

Meanwhile, the volume fraction of snow particles in bogie regions is much lower than 10% (Casa et al., 2014), and the Discrete Phase Model (DPM) based on Euler-Lagrange (E-L) method offers a more comprehensive picture of the particle flow interaction whose volume fraction is less than 10% (Paz et al., 2015), but requires more powerful computational resources (Zhang and Chen, 2007). Zhou et al. (2004), Wan et al. (2013), Ma et al. (2015) and Lai and Chen (2007) used DPM to simulate the movement of particles in airflow, and the simulation results showed good resemblance to these experimental results. Furthermore, Xie et al. (2017) and Wang et al. (2017, 2018) have investigated the snow accumulation on the single bogie surface utilizing DPM method. Thus, it is reasonable to use the DPM method to study the effect of snow accumulation on the bogies of high-speed trains.

In this paper, the DPM is used to simulate the motion of high-speed train in a cold and snowy atmosphere. The objectives of this study are to quantify the snow particles (with different ranges of snow particle diameter and density) accumulating on the bogies of high-speed trains (with different running speed) and to investigate how these parameters affects the snow accumulation on the bogie, focusing on the leading vehicle.

The selected geometric model, computational grids, computational domain and the conditions of the simulations of continuous phase and discrete phase are described in Section 2. In Section 3, the numerical method for the simulation of continuous phase and discrete phase are validated by wind tunnel tests, and the effect of bogie cut outs' shape, running speed of high-speed trains and snow particle density and diameter on the snow accumulation and particle movement characteristics are discussed. Finally, the conclusions are drawn in Section 4.

2. Numerical set-up

2.1. Geometry

The high-speed train model containing bogies, wheels and windshields is shown in Fig. 2, being a simplified version of the full-scale CRH2 train omitting the pantographs is adopted in this paper. According to the EN (CEN European Standard, 2013), the geometry model consists of the leading vehicle and part of additional coach can be used to investigate the flow structure around leading vehicle. Thus, the computational model adopted in this paper consists of the head car and