Research on the Influence of Unstable Incoming flow Parameters on DPF Regeneration Performance

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Abstract. Based on the simulation software, a regeneration simulation model of diesel particulate filter (DPF) was established, and the influence of unstable incoming flow parameters on its regeneration performance was studied. The results show that when the incoming flow is in an unstable state, the maximum temperature and maximum temperature gradient are lower than the steady state regeneration, with decreased regeneration efficiency. When the incoming flow temperature is in an unsteady state, 550 °C is the critical temperature. When the incoming flow temperature is lower than 550 °C, the maximum temperature and the maximum temperature gradient are higher than the steady state regeneration. When the incoming flow temperature is higher than 550 °C, the maximum temperature and the maximum temperature gradient has little difference, with regeneration efficiency higher than that of steady state regeneration. When the oxygen concentration of incoming flow is in an unstable state, the maximum temperature is higher than the steady state regeneration. The maximum temperature gradient is higher than the steady state regeneration when the oxygen concentration is lower than 15%, and the difference is not significant, and vice versa, with the regeneration efficiency higher than the steady state regeneration.

1. Introduction

Diesel engines have attracted much attention for their economical fuel, low CO2 emissions and reliable performance, while their particulate matter (PM) emissions are 30 to 80 times that of gasoline engines with the same displacement [1-2], which severely restricts the development of diesel engines. Recently, DPF is recognized as one of the most effective devices for reducing PM emissions, with its collection efficiency reaching more than 95% [3-4]. However, the deposition of particulate in its interior will increase the pressure at both ends of the DPF and affect the performance of the engine. Therefore, it is necessary to remove the deposited particulate [5-8], that is, regeneration technology. At present, numerical simulation is widely used to study the regeneration performance of DPF, for example, Lou Diming et al. studied the regeneration performance of the particulate filter during regeneration balance [2]; Song Qiang et al. studied the influence of incoming flow parameters on the regeneration performance of the carrier [9]; Meng Zhongwei et al. studied the influence of structural parameters on the regeneration performance [10]; Zheng Ming et al. studied the wall temperature field distribution during countercurrent regeneration [11]. However, the above studies are all lack of research on unstable state regeneration. Based on the simulation software, this paper establishes the DPF regeneration model, and calibrates the simulation model based on the experimental parameters. Using the corrected
model, the influence of the unstable state incoming flow parameters on the DPF regeneration performance is studied, which provides a reference for the optimization of the DPF control strategy.

2. Model establishment and verification

2.1. Model Introduction
The regeneration model of DPF is shown in Figure 1, of which Inlet is the entry condition, env is the environment, and DPF-1 is the calculation carrier. This paper studies the DPF steady state/unsteady state regeneration process by setting the inlet parameters.

![Figure 1. Regeneration model of DPF](image)

2.2. Model Verification
In order to verify the accuracy of the model, the DPF regeneration temperature field was measured with a bench. The comparison between the simulation value and the test value is shown in Figure 2. In the figure, 35-0 and 35-0.5 et al represent the internal position of the DPF, 0 and 1 represents the entrance and the exit, respectively. It can be seen from the figure that the simulated value and the test value are in good agreement in trend, and the maximum temperature is basically the same. The simulated value is 12°C lower than the test value (accounting for 1.44%), indicating that the model has good predictability and meets the simulation requirements. The main reason for the difference in the maximum temperature is that the simulation is one-dimensional, which can not actually reflect the temperature of the DPF in the third dimension.
2.3. Research Method

In the calculations in this paper, the carbon loading capacity of DPF is 5 g/L, and the flow range of incoming flow is: 5.6 g/s, 11.2 g/s, 16.8 g/s, 22.4 g/s, 28 g/s and 33.6 g/s, the incoming flow temperature range is: 500°C, 525°C, 550°C, 575°C, 600°C, and 625°C, and the incoming flow oxygen concentration range is 3%, 5%, 10%, 15% and 21%. Based on calculating regeneration performance of steady-state, in a fixed time increased to flow parameters to a certain value and maintain a steady state condition until the end of regeneration, which including incoming flow, incoming temperature and incoming oxygen concentration. The regeneration performance include maximum temperature, maximum temperature gradient, and regeneration efficiency. Table 1 shows the basic parameters of DPF.

| project                  | parameter          |
|--------------------------|--------------------|
| Carrier diameter/mm      | 144                |
| Carrier length/mm        | 152                |
| Hole density/CPSI        | 100                |
| Thickness of carrier wall/mm | 0.43            |
| Microporous diameter/mm  | 0.0125             |
| Porosity/%               | 0.48               |
| Permeability/mm²         | 5.5×10⁻¹³          |

3. Simulation Results Analysis

3.1. Influence of Unstable Incoming Flow on Regeneration Performance

The relationship between DPF regeneration performance and incoming flow is shown in Figures 3 to 4. It can be seen from Figure 3 that during stable-state regeneration, as the incoming flow rate increases, the maximum temperature and maximum temperature gradient decrease, while the flow rate is small, the maximum temperature gradient decreases rapidly. The reason why is that, due to the increase of the incoming flow rate, although the supply of oxygen to the incoming flow rate is improved, the convective heat exchange intensity with the carrier is also enhanced at the same time. During unstable state regeneration, with the increase of incoming flow, the change trend of the maximum temperature and maximum temperature gradient is consistent with that of stable state regeneration. However, the maximum temperature and maximum temperature gradient of unstable state regeneration are slightly smaller than the original stable state regeneration value. Due to the sudden increase of the incoming flow during the regeneration process, the convective heat transfer strength inside the carrier suddenly
increases, and the unevenness of the radial velocity of the gas in the carrier increases. It can be seen from Figure 4 that with the increase of the incoming flow, the regeneration efficiency shows a linear downward trend, and the regeneration efficiency of the unstable state regeneration is lower than that of the unstable state regeneration. Due to the increase of the incoming flow during the regeneration process, the ability to transfer the regeneration temperature peak is weakened, and the time for maintaining the hot zone is shortened.

3.2. The Influence of Unstable Incoming Flow Temperature on Regeneration Performance
The relationship between DPF regeneration performance and incoming flow temperature is shown in Figures 5 to 6. It can be seen from Figure 5 that during stable state regeneration, as the incoming flow temperature increases, the maximum temperature first increases and then gradually becomes flat. The maximum temperature gradient first increases and then gradually decreases. Owing to the increase of the incoming flow temperature, the reaction rate of soot and oxygen is obviously increased, and when it increases to a certain value, the reaction rate of soot and oxygen will reach a fixed value. At this time, the regeneration of particulates in the carrier is more uniform and the temperature gradient is reduced when increase the incoming flow temperature. During unstable state regeneration, with the increase of the incoming flow temperature, the change trend of the maximum temperature and the maximum temperature gradient is approximately the same as the steady state regeneration. 550℃ is set as the critical temperature under current conditions. When the incoming flow temperature is less
than 550°C, the maximum temperature and the maximum temperature gradient are both greater than the value of the stable state regeneration, while the temperature is greater than 550°C, the maximum temperature is not much different from the stable state, and the maximum temperature gradient is less than the value of the stable state regeneration, as the temperature change causes the soot reaction rate to increase sharply, when the incoming flow temperature is less than 550°C. On the contrary, even if the temperature is increased, the reaction rate gradually stabilizes. It can be seen from Figure 6 that as the incoming flow temperature increases, the regeneration efficiency gradually increases, and the regeneration efficiency of the unstable state regeneration is greater than the regeneration efficiency of stable state. The reason why is that the increase of the incoming flow temperature increases the soot reaction rate during unstable state regeneration.

Figure 5. The influence of the unstable incoming flow temperature on the maximum temperature and maximum temperature gradient

Figure 6. The influence of unstable incoming flow temperature on regeneration efficiency

3.3. Influence of Unstable Incoming Oxygen Concentration on Regeneration Performance

The relationship between DPF regeneration performance and incoming oxygen concentration is shown in Figures 7 to 8. It can be seen from Figure 7 that during stable state regeneration, as the oxygen concentration increases, the maximum temperature gradually rises and the maximum temperature gradient first increases and then gradually becomes gentle. As the concentration of incoming oxygen increases, the reaction rate of soot and oxygen increases, and the heat release rate increases. During unstable state regeneration, as the incoming oxygen concentration increases, the trends of the maximum temperature and the maximum temperature gradient are approximately the same. The
maximum temperature is higher than the stable state regeneration. When the oxygen concentration is less than 15%, the maximum temperature gradient is higher than the steady state regeneration. There is little difference of the two when the oxygen concentration is greater than 15%. As the incoming oxygen concentration is increased during the regeneration process, the reaction rate suddenly increases and the heat release rate increases. It can be seen from Figure 8 that as the concentration of incoming oxygen increases, the regeneration efficiency gradually increases, and the regeneration efficiency of the unstable state regeneration is higher than that of the stable state regeneration, due to the increase of the heat release rate, leading by the oxygen concentration.

![Figure 7. The influence of unstable oxygen concentration on the maximum temperature and maximum temperature gradient](image)

![Figure 8. The influence of unstable oxygen concentration on regeneration efficiency](image)

### 4. Conclusion

Based on simulation software, a DPF regeneration model was established, and the influence of unstable incoming flow parameters on DPF regeneration performance was studied. The following conclusions were obtained:

- The first one is that the maximum temperature and maximum temperature gradient are both lower than the steady state regeneration when the incoming flow is in an unstable state. And the regeneration efficiency is reduced.
- The second one is that 550℃ is the critical temperature when the incoming flow temperature is unstable. The maximum temperature and maximum temperature gradient are higher than the steady state regeneration when the incoming flow temperature is lower than 550℃, the
maximum temperature and the maximum temperature gradient is not much different when the incoming flow temperature is higher than 550℃. The regeneration efficiency is increased.

- The third one is that the maximum temperature is higher than the stable state regeneration when the incoming oxygen concentration is unstable, and the maximum temperature gradient is higher than the steady state regeneration when the oxygen concentration is lower than 15%, and vice versa, the difference between the two is not significant. The regeneration efficiency increases.

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