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Research on particulate filter simulation and regeneration control strategy

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ABSTRACT

This paper reports a DPF (Diesel Particulate Filter) collection mathematical model for a new regeneration control strategy. The new strategy is composed by main parts, such as regeneration time capturing, temperature rising strategy and regeneration control strategy. In the part of regeneration time capturing, a multi-level regeneration capturing method is put forward based on the combined effect of the PM (Particulate Matter) loading, pressure drop and fuel consumption. The temperature rising strategy proposes the global temperature for all operating conditions. The regeneration control process considers the particle loading density, temperature and oxygen respectively. Based on the analysis of the initial overheating, runaway temperature and local hot spot, the final control strategy is established.

1. Introduction

Diesel Particulate Filter (DPF) is widely known as an effective exhaust-particle post-processing equipment. However, when the particles are accumulated to a certain level, exhaust resistance and the DPF pressure drop will increase, which can consequently pose a adverse impact on fuel economy and output power [1,2]. Thus, timely removal of these particles is highly desired so as to achieve DPF regeneration process. In this article, a new control strategy for regeneration process is built from DPF regeneration time, temperature rising strategy and control strategy of regeneration process [3,4].

Since the vehicle running conditions is transient and complicated, there are still multiple big difficulties for the DPF regeneration time determination [5,6]. Based on the Particulate Matter (PM) load model, the pressure drop method or fuel consumption method, traditional DPF regeneration control strategy determines the regeneration time, yet it is unable to accurately predict the amount of PM loading as well as the lack of the optimal temperature rising control strategy. Additionally, insufficient care is taken towards the runaway regeneration and hot spot phenomena, which will easily cause damage to the DPF carrier and thus reduce its service life [7,8].

Firstly, a new method called "multi-level regeneration time determination", which couples three traditional methods including the PM loading mathematical model method, the pressure drop method and fuel consumption method, is put forward to enhance the accuracy of regeneration time control and solve these problems. Along with the appropriate temperature rising, methods are determined to achieve "two temperature" (e.g. Diesel Oxidation Catalyst (DOC) inlet temperature and DPF inlet temperature) as well as temperature rising rate requirements according to the specific engine operating conditions. Finally, the appropriate method of controlling the DPF temperature distribution is determined. The

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Nomenclature

E	Collection efficiency
E_0	Collection efficiency of fresh DPF
E_{cake}	Collection efficiency of cake layer
w_{cake}	Thickness of particle layer
d_{ccake}	Diameter of microspheres
w	Wall thickness
w_s	Thickness of particle layer
Q	Exhaust volumetric flow rate
L	Length of carrier's channel
D_f	Diameter of the carrier
k_0	Permeability coefficient of wall
k_{soot}	Permeability coefficient of particle layer
b	Side length of outlet channel
f_{CO}	Selective coefficient of CO
C_{in}	Inlet PM concentration for DPF
C_{out}	Outlet PM concentration for DPF
K_R	Reaction rate of the PM
T_{in}	DPF inlet exhaust temperature
T_{out}	DPF outlet exhaust temperature
$\dot{Q}_r$	Energy released by the oxidation
$\dot{q}_{trans}$	Heat released to the environment from DPF
ΔH_{CO}	Formation enthalpy of CO
ΔH_{CO2}	Formation enthalpy of CO_2
A_0	Frequency factor
E_0	Chemical reaction activated energy
y_{O2}	Molar fraction of O_2 in the exhaust
A_p	Frequency factors of thermal reaction
A_a	Frequency factors of catalytic reaction
E_p	Thermal reaction's activated energy
E_a	Catalytic reaction's activated energy
$c_{p,\ filter}$	Specific heat capacity of the carrier's material
ρ_{filter}	Density of the porous medium

DPF regeneration control strategy proposed in this paper can accurately predict the amount of PM load, based on which determines the appropriate regeneration timing and proper temperature mode. Further, it can achieve precise control of the DOC inlet temperature, the DPF inlet temperature and the rate of temperature rise. Compared with other DPF regeneration control strategies, the control strategy proposed in this paper have finally realized the reasonable distribution of DPF temperature and made the regeneration process faster, safer and more efficiently.

2. DPF model

2.1. PM collection model

As shown in Fig. 1, the DPF carrier's wall is discretized into some slabs with the same thickness. It is assumed that every slab contains the same amount of unit collectors with the same size and collects particles by themselves.

The collection efficiency E of fresh DPF is drawn from Fig. 1, which can be expressed as:

$$E = \frac{m_{in}-m_{out}}{m_{in}} = \frac{m_{in}-(1-E_i)m_i}{m_{in}} = \frac{m_{in}-(1-E_i)(1-E_{i-1})(1-E_{i-2})L(1-E_l)m_{in}}{m_{in}}$$
$$= 1-(1-E_i)(1-E_{i-1})(1-E_{i-2})L(1-E_l) \tag{1}$$

Assuming that the carrier's wall is composed by an infinite number of slabs and the direction of airflow movement is the positive direction of the x-axis in the figure, then the fresh DPF collection efficiency E by integrating is:

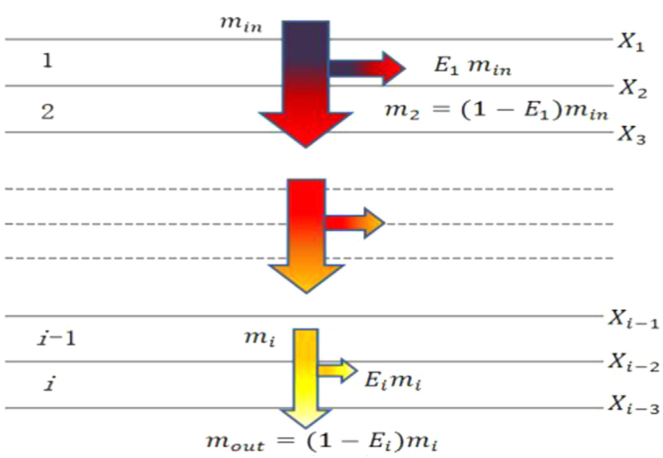

Fig. 1. Fresh DPF carrier's wall which is discretized into a number of slabs.

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