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Research Paper

# Reducing HC emissions from a gasoline engine at the starting conditions through activated carbon adsorption

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## HIGHLIGHTS

- Three kinds of activated carbon materials are selected to adsorb HC emissions.
- The adsorption is investigated at different starting coolant temperatures.
- The adsorption abilities in the repeated engine starting test are investigated.
- The adsorption processes could be divided into three different phases.
- HC emissions are obviously decreased by adsorption.

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## ABSTRACT

The general purpose of this work is to examine the adsorption characteristics of activated carbon materials for reducing HC emissions from the gasoline engine under starting conditions. Three kinds of activated carbon materials were selected to adsorb HC emissions within 80 s from the onset of starting at different coolant temperatures of 25, 35, 45 and 55 °C, respectively. The experimental results showed that the total HC adsorption rates of activated carbon materials declined with the increase of coolant temperatures. The total HC adsorption rates of activated carbon honeycomb, foams and fibers were 68.6%, 66.1% and 53.5% under the coolant temperature of 25 °C. The early desorption was found for activated carbon foams, which was getting severe with the increase of coolant temperatures. Then, the adsorption performance of activated carbon honeycomb was further investigated at the repeated engine starting conditions. Under the repeated starting conditions, the total HC adsorption rates of activated carbon honeycomb decreased with the increase of adsorption times in the test. The total HC adsorption efficiencies of the first three times under repeated starting conditions were 76.4%, 63.7% and 54.0%, respectively. The results showed that the adsorption processes could be divided into three phases based on the adsorption characteristics, which were rapid adsorption phase, interim adsorption phase and slow adsorption phase, respectively.



## 1. Introduction

In recent years, reducing hydrocarbon emissions (HC) emitted from automotive vehicles has attracted more and more attentions [1–3]. For gasoline engines, most of HC emissions could be converted to harmless products effectively by an on-board Three Way Catalyst (TWC) while the exhaust temperature exceeding its light-off temperature of 200–300 °C [4,5]. However, as the TWC could not achieve the light-off temperature quickly [6,7], the engine may expel large amounts of HC emissions during the cold [8] and even warm starting conditions. It was reported that, during the New European Driving Cycle (NEDC) cycle, 70–90% HC emissions were resulted from the engine starting due to the inefficient TWC conversion and rich combustion [9–11].

So far, many studies have been carried out on different approaches for reducing HC emissions produced during the starting period [12–16]. Ji et al. tried to improve the engine performance by the addition of alternate fuel such as hydrogen, Dimethyl ether (DME) and methanol. The experimental results showed that the addition of alternate fuel helped improve thermal efficiency and reduce HC emissions during the cold start. However, the engine produced more NOx emissions because of the increased H/C ratio and elevated combustion temperature [17–20]. Kato et al.

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studied the performance of an electrically heated TWC. They found that the electrically heated TWC could be more effective on reducing HC emissions during the cold start, because heating the TWC by electrical equipment could help it quickly achieve the light-off temperature [21,22]. It is seen from above investigations that HC emissions during the cold could be reduced by either improving the fuel quality [23,24] or heating the TWC by electrical methods. However, for mono-fuel gasoline engine, it is hard to reduce HC emissions by adopting dual fuel strategy which generally requires the recalibration of control unit and the addition of secondary fuel supply system. Heating TWC before starting is effective on improving the TWC conversion efficiency by enabling it to quickly reach the light-off temperature, however, this method would lead to the increase in energy consumption of the engine. Besides, the engine starting time would be prolonged because it costs time to heat the TWC.

When the fluid contacts the porous solid, one or multiple components of the fluid could be adhered to the surface of the solid due to the molecular inter-atomic forces. This phenomenon is called adsorption. Adsorption is present in many natural, physical, biological and chemical systems, which is widely used in industrial applications such as the activated charcoal, capturing and using waste heat to provide cold water for air conditioning and other process requirements [25]. Generally, for a specified material, the adsorption could be occurred under high pressure and low temperature conditions, whereas desorption could be taken place under low pressure and high temperature conditions. The above characteristics of absorber makes it could efficiently adsorb HC emissions to the surface of sorbent. Compared with adopting TWC, reducing HC emissions by absorber could be accomplished at low temperatures. These make the absorber is more practical to be used for controlling HC emissions during the cold start. Westermann et al. studied the relative ability of some well-selected zeolitic materials for reducing HC emissions during the simulated cold start conditions. The results showed that even in the presence of some potential inhibitors such as water, the adsorption capacities of zeolitic materials at low temperatures were overall increased with the acidity of zeolites [26]. Yamazaki et al. developed an active-type HC adsorption system and tested its performance. The results showed that HC emissions in the Federal Test Procedure (FTP) testing cycle were reduced by more than 70% as compared to a system without the HC adsorption system [27]. Mukai et al. studied the adsorption characteristics of zeolite based absorber to control HC emissions from a gasoline engine by using model gas of $N_2$, $C_3H_6$, $C_7H_8$ and $H_2O$. According to the test results, approximately 90% of the total amount of HC modeling gas was immediately stored in the zeolite based absorber after the cold start [28].

Activated carbon materials are widely used [29–31] in the field of gas or liquid purification because of its high specific surface, developed pore structure, stable surface chemical properties, strong adsorption and so on. These characteristics also make the activated carbon become an effective and feasible adsorption material for reducing HC emissions at the engine starting condition. However, present researches on the applications of adsorption to reduce HC emissions during cold start are mainly focused on the surface modification of sorbent or the simulation of adsorption process. Few studies reported the activated carbon on adsorbing HC emissions under the real engine conditions. As the starting process of internal combustion engine is quite complex [32], which is hard to be simulated under non-engine conditions, it is of necessity to experimentally investigate the performance of activated carbon on HC adsorption in real engine conditions. In this investigation, three kinds of representative activated carbon materials of activated carbon honeycomb, activated carbon fibers and activated carbon foams were selected to examine the ability of adsorbing HC at different coolant temperatures. The material with the best adsorption performance was further investigated under the repeated engine starting conditions to check its durability in adsorbing HC emissions.

## 2. Experimental setup and procedure

### 2.1. Activated carbon materials

Three kinds of active carbon are adopted in this test, which are activated carbon honeycomb, activated carbon foams and activated carbon fibers, respectively. The pictures of activated carbon materials used in this experiment are shown in Fig. 1. The shape and density of the selected activated carbon materials are different. Amounts of adsorption materials are selected to keep the relative exhaust back pressure around 14 kPa which is equivalent to the exhaust pressure of the original engine with the TWC. Under this relative pressure, volumes of activated carbon honeycomb, foams and fibers are $100 * 100 * 100$, $100 * 100 * 150$ and $100 * 100 * 6$ mm, respectively. The specifications of activated carbon materials are listed in Table 1.

The schematic of experimental setup is shown in Fig. 2. It is seen from Fig. 2 that the adsorption device is connected parallel with the exhaust pipe in order to preserve the pore structures of activated carbon materials from damages caused by the high exhaust temperature. When the engine starts, the Electronic Control Unit (ECU) opens valve B and C and closes valve A to make exhaust gases pass the adsorption device along the red arrow direction. Thereby, HC emissions produced during the starting period could be adsorbed. When the TWC achieves its light-off temperature, the ECU opens valve A and closes valve B and C. The exhaust gases are controlled to pass the exhaust pipe along the black arrow direction to enable the harmful emissions to be converted effectively by the TWC. The engine used in this experiment is a 1.5 L spark-ignition engine made by Beijing Automotive Industry Corp (BAIC), whose specifications are listed in Table 2. The engine is loaded by a CAC (a type of AC electrical dynamometer) eddy current dynamometer manufactured by Power link and the uncertainty is ±1 rpm in engine speed detection. The coolant and ambient temperatures are measured by a FC2210 data acquisition unit manufactured by Power link and the uncertainty is ±1 °C. HC emissions are recorded by a Horiba 584L emissions analyzer which sensitivity is 1 ppm. HC emissions are sampled and measured on both sides of the adsorption device. The adsorption ability is can be shown by the difference in data. In the tests, each adsorption material is used only once (the material used in the adsorption test of the consecutive engine starting is exceptional).

### 2.2. Experimental procedure

During the experiment, the ambient temperature and pressure were 25 °C and 101 kPa, respectively. The engine was started under different coolant temperatures of 25, 35, 45 and 55 °C to explore the effects of different activated carbon materials on HC adsorption under the starting conditions. According to the adsorption abilities of activated carbon materials, material with the best adsorption performance was further investigated under the repeated starting conditions at a given starting coolant temperature of 15 °C and pressure of 101 kPa to check its adsorption efficiency under frequently starting conditions. In the adsorption test of repeated engine starting, the engine was started consecutively seven times to observe the variations of HC emissions with the increase of starting times.