한국에너지공학회지(2004), 제13권 제2호
Energy Engg. J(2004), Vol. 13, No. 2, pp. 161~165

A Study on Evaporative Emissions in a Spark Ignition Engine with a Carbon Canister

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Abstract — Evaporative emissions from gasoline powered vehicles continue to be a major concern. The performance of carbon canister in evaporative emission control systems has become an important aspect of overall fuel system development and design. A vehicle's evaporative emission control system is continuously working, even when the vehicle is not running, due to generation of vapors from the fuel tank during ambient temperature variations. In this study, the effects of evaporative emissions on the engine performance were investigated. The experimental results show the effectiveness of this system for future exhaust emissions and enhanced evaporative emissions. This paper discusses the evaluation on the relationship between carbon canister condition and engine performance while engine is running.

1. Introduction

Evaporative hydrocarbon emissions from gasoline-powerd vehicles continue to be a major concern in areas where the national ambient air quality standard for ozone is violated. Lyons *et al.*[1] reported that evaporative emissions are generally grouped into the following basic categories: running losses, hot soak emissions, and diurnal emissions. The latter category is usually divided into two subcategories: resting losses and pressure-driven diurnal emissions.

A vehicle's evaporative emission control system is continuously working, even when the vehicle is not running, due to generation of vapors from the fuel tank during ambient temperature variations[2]. Diurnal temperature cycles cause the fuel tank to breathe the fuel vapor in and out, and thus the activated carbon canister is constantly loading and purging the hydrocarbon vapors[3].

Technologies for reducing evaporative emissions generated from fuel vapor have been developed. To reduce evaporative emissions, both permeation from fuel and vapor lines and breakthrough from the evaporative canister need to be diminished. Fewer fuel line connections are used and hose and valve materials have been modified to reduce permeation[4].

Ghe *et al.*[5] proposed one-dimensional carbon canister adsorption model has been developed to assist in the prediction of the performance of carbon bed canisters in vehicle evaporative emissions control systems. The model accounts for mass transfer and transient thermal phenomena, both of which are found to be essential in accurately describing canister behavior. The model assumes the vapor above the carbon to be in equilibrium with the adsorbed mass while the local temperature is determined by the dynamic balance between the heat of adsorption, carbon heat capacity and heat loss to ambient.

For the loading and purging of the canister evaporative gas when it is installed on a vehicle, the amount of purge air, loading rate, and other such characteristics must be clarified[6]. In addition, the effects on the engine during loading and purging must be understood so that the canister can be designed to take full advantage of the loading and purging characteristics.

Recently, numerical calculation has allowed canister purge algorithm with a virtual HC sensor[7] and several studies have reported a carbon canister model.

The objective of this paper is to evaluate the relationship between carbon canister condition and engine performance during engine operation, and other such fundamental data for the canister during loading and purging are needed, and this data will prove valuable in the development of the canister.

2. Experimental Apparatus and Method

2-1. Structure of Canister

Figure 1 shows the cross-sectional view of the canister and the measurement locations. There are three openings to the canister: inlet for the evaporation gas to enter from the fuel tank, exit leading to the intake port of the engine, and a purge port for the clean external air. On the top and bottom sections of the cylindrical canister are 3 mm thick filters and a grid, and there is an air gap between the filter and the port. The interior of the canister is filled with activated carbons.

2-2. Experimental Apparatus

In order to understand the flow characteristics of the evaporation gas within the canister, a flow characteristic testing apparatus was constructed as shown in Fig. 2. A vacuum pump was used to inject and extract air to simulate loading and purging conditions. The flow rate of this air was measured using a laminar flow meter, and the velocity distribution within the canister was measured using a constant temperature anemometer. Temperature was measured using a platinum hot wire probe with a diameter of 5 μm, and the measurement locations were 20 mm and 60 mm from the top and 40 mm and 80 mm in the vertical direction, for a total of four locations at 10 mm depth increments measuring the velocity in the radial direction.

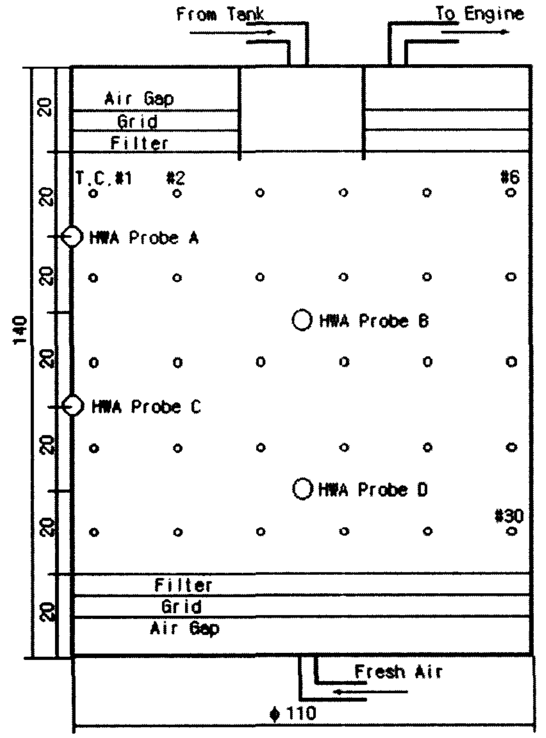

Fig. 1. Schematic diagram of the canister and the measurement locations.

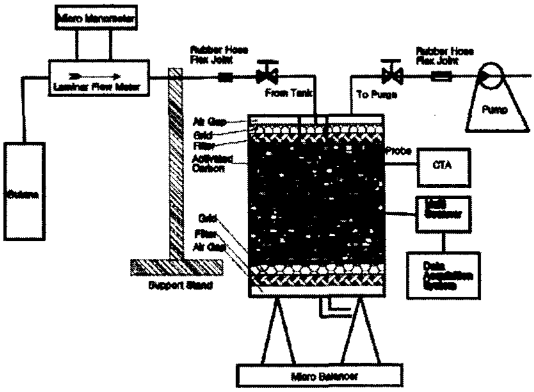

Fig. 2. Schematic drawings of the canister systems.

To clarify the temperature distribution characteristics within the canister at loading and purging, a total of 30 T-type thermocouples were installed and shown in Fig. 1. Temperature measurements were taken at 10 second intervals and data was acquired using Chartview. Pressure loss was measured with a pressure gauge located at each port.

During loading, the vacuum pump was connected to the fresh air part of the canister with the purge valve closed, and flow was controlled using the inlet valve and measured using a laminar flow meter. During purging, the location of the vacuum pump was switched, and the air was purged at the same flow rate. Loading was performed in four steps at 0.3 *l*, 0.6 *l*, 0.9 *l*, and 3 *l* per minute while purging was done in four steps at 6.0 *l*, 7.8 *l*, 15.0 *l*, and 21.0 *l* per minute.

3. Results and Discussion

For the loading and purging of the canister fuel

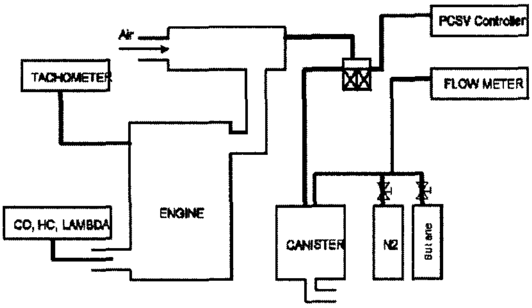

Fig. 3. Schematic diagram of experimental apparatus.

vapor when it was installed on a vehicle, it must be clarified. In addition, the effects on the engine during loading and purging must be understood so that the canister can be designed to take full advantage of the loading and purging characteristics. The engine used in this experiment was HMC's 1.8 DOHC. To control the hydrocarbon concentration that flows in afterwards, the amount of nitrogen was the adjusted proportion. The experiments were performed in three steps at nitrogen versus hydrocarbon per volume proportions 100/0, 75/25, and 50/50.

Figure 3 shows the schematic diagram of the experimental apparatus. The engine speed was increased from 850 rpm (revolution per minute) to 2500 rpm. To clarify the canister characteristics, engine speed variations, stability, CO, and HC emissions were measured when the simulated evaporative hydrocarbon flowed into the canister.

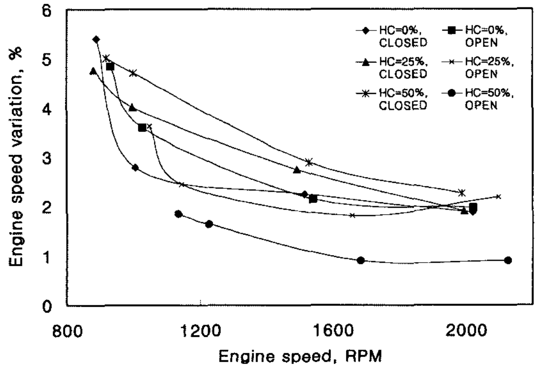

Fig. 4. Engine speed variation with different evaporated hydrocarbon flow.

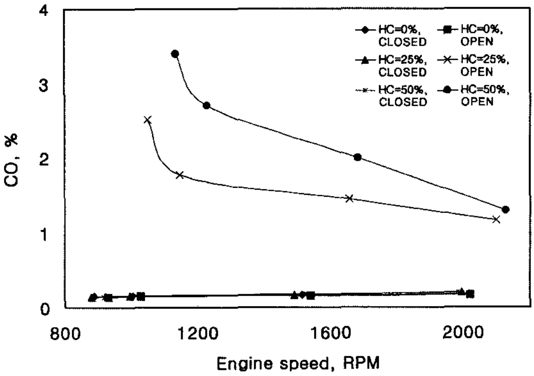

Fig. 5. Carbon monoxide with different evaporated hydrocarbon flow.

Figure 4 shows engine speed variation as a function of inflow of hydrocarbon to the canister. The engine speed variation is defined as the half of difference between maximum engine speed and minimum engine speed during a specified period into mean engine speed. The open and the closed of the legend in this figure are defined as open and closed of the purge control solenoid valve (PCSV). In case of 0% hydrocarbon, engine speed variation increases a small quantity, but the engine speed variation decreases in 25% and 50% of the evaporative hydrocarbon. Since the engine speed increases as the supply of the evaporative hydrocarbon is increased, the engine speed variation is getting smaller and the stability can be increased.

In Fig. 5, CO emissions versus engine speed was plotted. It shows the trends of CO emissions according to the evaporative hydrocarbon supply during the engine operation. CO emissions in this figure are high since hydrocarbon increases according to opening the purge control solenoid valve (PCSV), and CO emissions are high as engine speed is low. The reason for the increase in CO emissions could be the lack of oxygen increase with the increase of fuel gas supplement in inlet system which results in the incomplete combustion.

Figure 6 shows the trends of hydrocarbon emissions according to the evaporative hydrocarbon supply during the engine operation. Therefore the inflow of evaporative emissions makes the engine speed high and the speed variation low, but CO emissions and HC emissions increase. In particular, accurate control

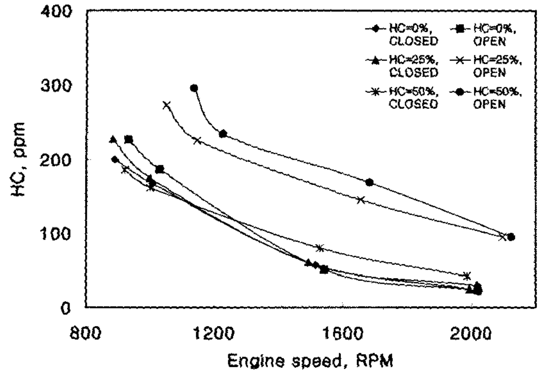

Fig. 6. Hydrocarbon emissions with different evaporated hydrocarbon flow.

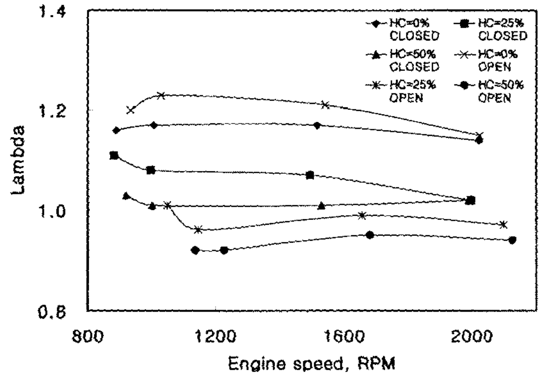

Fig. 7. Lambda with different evaporated hydrocarbon flow.

for inflow of fuel vapor at idling is required.

The lamda was plotted with variation of engine speeds in Fig. 7, When the PCSV was open in 0% hydrocarbon, air-fuel ratio shows lean. But it shows that the lambda shows rich according to 25% or 50% of the evaporated hydrocarbon. The trends are increased as rate of hydrocarbon increases and engine speed is low.

Figure 8 shows lambda as a function of the PCSV hydrocarbon concentration. In order to avoid degradation of the lambda control and the pollution emissions levels, the purged hydrocarbons must be evenly distributed among the cylinders and mixed as thoroughly as possible with the intake air. In the carbon canister systems, the purging air flow through the active carbon canister is mixed with the intake air flow. Based on the purge characteristics of standard carbon canisters and on the hydrocarbon levels in a fully charged carbon canister, and using a spark ignition engine, the operating frequency of the canister purge valve and the inlet point of the purge flow into the intake manifold were varied, using n-butane as the hydrocarbon. The measurements taken for HC emissions and the lambda in the exhaust manifold shows that the PCSV controller and the design of the carbon canister affect mixture and engine's HC emissions.

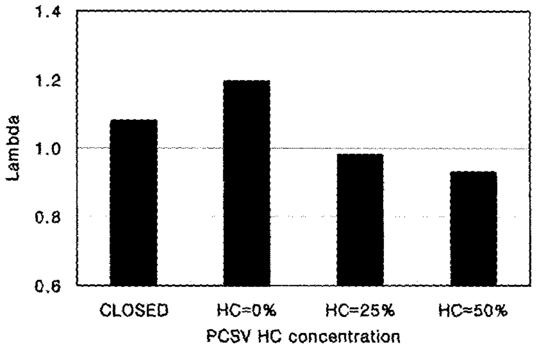

Fig. 8. Lambda vs. PCSV hydrocarbon concentration.

4. Concluding Remarks

The effects of evaporative emissions on the engine performance were investigated in this work. The conclusions for this work include:

(1) In case of 0% hydrocarbon, engine speed variation increases a small quantity, but the engine speed variation decreases in 25% and 50% of evaporated hydrocarbon. Since the engine speed increases as the supply of hydrocarbon is increased, the engine speed variation is getting smaller and the stability can be increased.

(2) CO emissions are high since hydrocarbon increases according to opening the PCSV, and CO emissions are high as engine speed is low. The inflow of evaporative emissions makes the engine speed high and the speed variation low, but CO emissions and HC emissions increase. In particular, accurate control for inflow of fuel vapor at idling is required.

(3) The lambda variation without supplementary hydrocarbon supply is continuously zero but lambda variation increases greatly at 25% or 50% of the evaporated hydrocarbon. The lambda variation seems

to be large in low engine speed or idling, and small as engine speed is increased. The measurements taken for HC emissions and the lambda in the exhaust manifold show that the PCSV controller and the design of the canister affect mixture and engine's HC emissions.

Acknowledgments

This work was supported by the Ministry of Science & Technology (MOST) and the Korea Science and Engineering Foundation (KOSEF) through the Center for Automotive Parts Technology (CAPT) at Keimyung University in Daegu, Korea.

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