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Methods for Fast Catalytic System Warm-Up During Vehicle Cold Starts

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Abstract: During vehicle cold start, emissions, mass flow rates, and catalytic converter space velocities vary by orders of magnitude. Therefore, catalytic exhaust control systems must be designed to operate at high efficiency almost from the moment of engine start-up. Catalysts must reach their operating temperature as quickly as possible. Therefore, the utility of different methods for improving the warmup characteristics of catalytic systems is illustrated.

A very elegant method to speed the warmup is the use of the engine itself as a "preheater" for the catalytic converters. High exhaust gas enthalpy to raise exhaust system mass up to its operating temperature is obtained by the use of extreme spark retard, stochiometric mixtures, and fully opened throttle. Intensive studies to investigate the effects of concurrent changes of spark timing and air/fuel mixtures on exhaust gas temperature, enthalpy, NO_x and HC emissions are discussed.

Finally, NO_x catalyst characteristics are dealt with, because the NO_x catalyst is the first in a dual-bed catalytic system. The NO_x catalyst should have high activity, low ignition temperautre, and good warmup performance. If the NO_x has a fast warmup rate, this would result even in a significant improvement in the warmup characteristic of the HC/CO bed.

Sector: Automotive

Topic: Emissions control

Methods for Fast Catalytic System Warm-Up During Vehicle Cold Starts

720481

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INTRODUCTION

To achieve the emission targets prescribed by law for 1975/76 a number of emission concepts with conventional internal combustion engines and emission control systems have been examined by the automotive industry. Catalytic converters, thermal reactors and a combination of these two have been considered as emission control systems (1)*. Low emission values have been attained with these concepts when the engine is under warm working condition. However, the difficulties lie mainly in the warm-up phase during cold vehicle start-up.

To improve the over-all effectiveness of catalytic systems at vehicle start-up, extensive experimental tests were carried out during the warm-up phase on various after burning systems by the Research Department of the Volkswagenwerk AG. The intent of this paper is to illustrate the utility of improving the warm-up characteristic of catalytic emission control systems for achieving very low emission levels.

ABSTRACT

During vehicle cold start, emissions, mass flow rates, and catalytic converter space velocities vary by orders of magnitude. Therefore, catalytic exhaust control systems must be designed to operate at high efficiency almost from the moment of engine start-up. Catalysts must reach their operating temperature as quickly as possible. Therefore, the utility of different methods for improving the warm-up characteristics of catalytic systems is illustrated.

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*Number in ( ) indicates reference at end of paper.

WARM-UP METHODS FOR CATALYTIC SYSTEMS

Catalytic emission control systems described in this paper operate mainly with the dual-bed catalytic process. The first bed contains the reduction catalyst which reduces the oxides of nitrogen (NO_x) by carbon monoxide (CO), hydrogen (H_2), and hydrocarbons (HC) which are present in the exhaust gases. The reaction between NO_x and CO will only take place providing that the amount of oxygen (O_2) present in the exhaust gas is strictly limited to low concentrations. This oxygen limitation is met by adjusting rich fuel/air mixtures.

The second catalyst bed contains the oxidation catalyst which burns the carbon monoxide and hydrocarbons after introducing secondary air between the first and second beds. The quantity of secondary air is set high enough to ensure that there is excess oxygen for all driving conditions.

Figure 1 illustrates a dual-bed axial-flow converter. Such a concept using fresh catalysts when tested according to the CVS cold-hot test procedure gave emission values which were still twice as high as the exhaust emission standards specified for model year 1976. The results would be considerably better if the catalytic emission system could be warmed up very quickly from the moment of cold engine start-up. Methods to speed the warm-up are listed below:

- Reduce the heat capacity of the exhaust system between the engine and the dual bed converter.
- Reduce the heat capacity of the catalyst, use smaller catalyst quantities, and smaller catalyst particles.
- Mount the converter very near to the engine exhaust valves.
- Introduce secondary air in front of the first bed during the initial 120 seconds after cold engine start-up; then switch the secondary air to the connecting pipe between NO_x and HC/CO beds (staged secondary air).

Even when these features were used, the dual-bed system illustrated in Figure 1 could not reach the targets of 0.41 gm. HC/mi., 3.4 gm. CO/mi., and 0.4 gm. NO_x mi. as proposed in the Federal Register for 1976.

It is particularly difficult to fulfill the emission standard for oxides of nitrogen as the temperature in the NO_x bed increases very slowly in systems which are designed to allow an adequate residence time for the exhaust gases. In Figure 2 is illustrated the mid-bed temperature of a VW radial-flow converter with a 1.3 liter NO_x bed during the CVS cold start. It is plain to

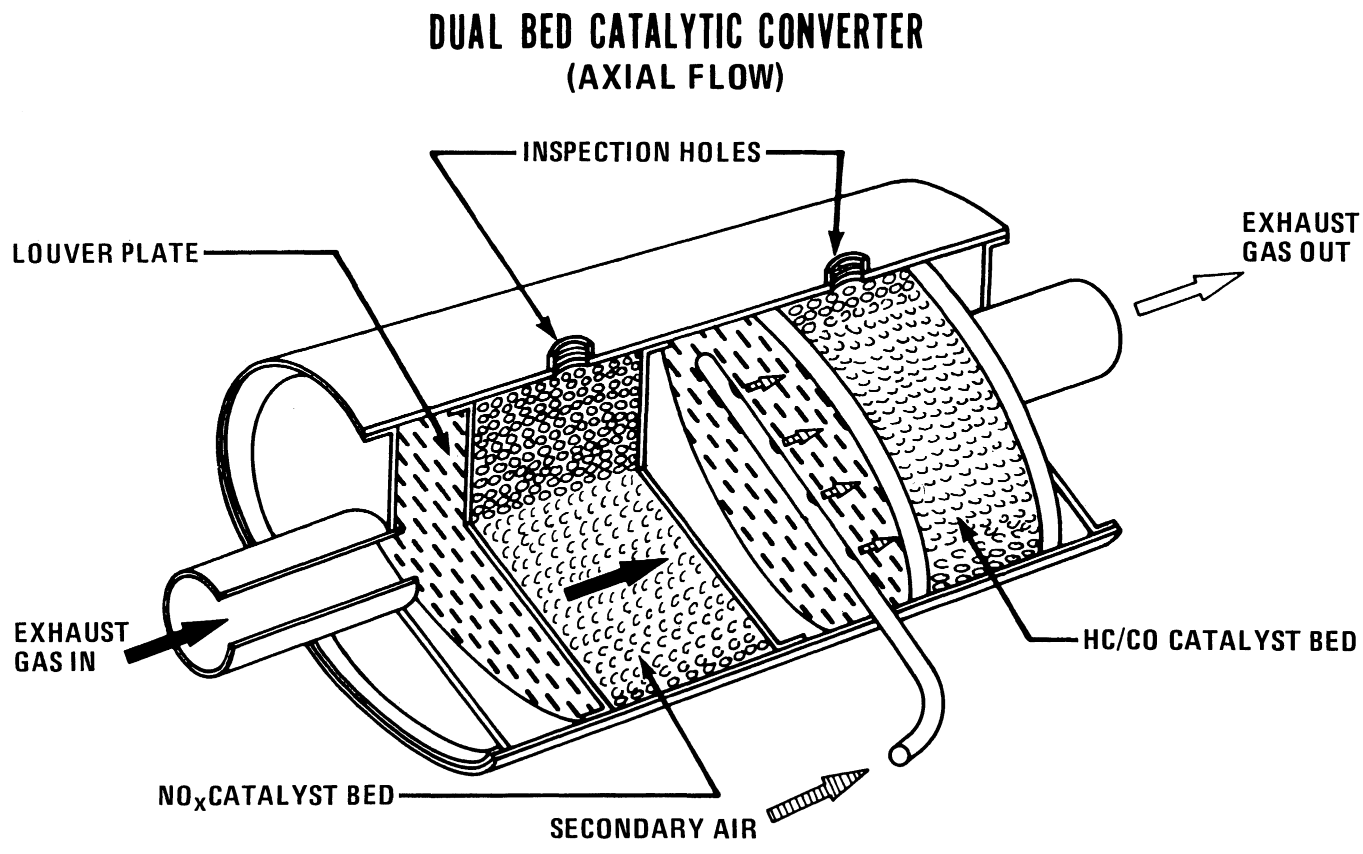

Figure 1

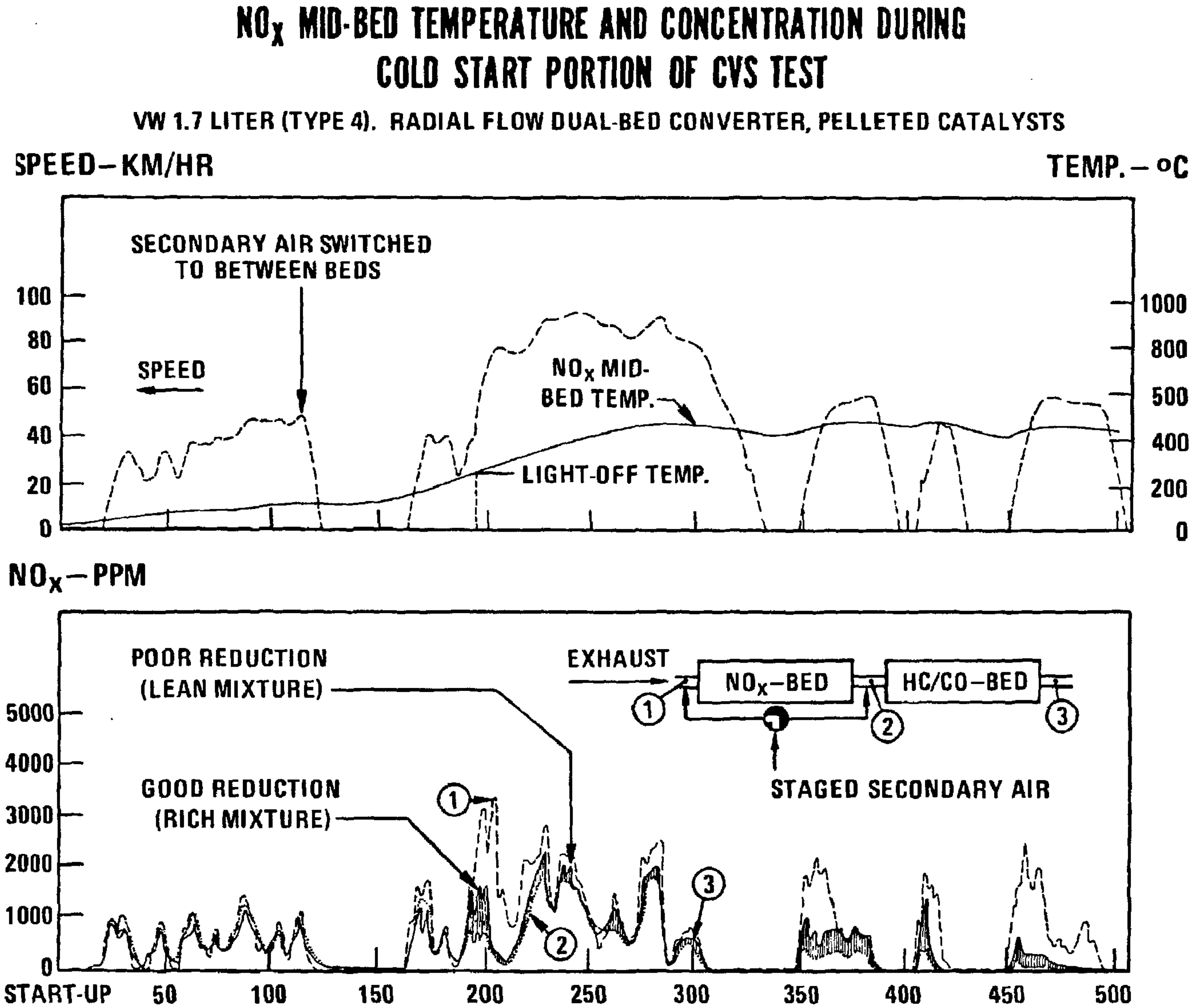

Figure 2

see that the catalyst ignition temperature of approx. 250°C was reached in the pelleted NO_x catalyst bed after 195 seconds in spite of the use of the staged secondary air feature. The ammonia problem can also be seen in Figure 2 although this is not being dealt with in this connection. For more detailed information refer to Meguerian (2).

To illustrate the problems of catalytic exhaust emission control systems Figure 3 shows the tail pipe emissions as well as the exhaust gas flow rate during the first 240 sec. of a CVS cold start test. Both the concentrations and the mass flow rate vary by orders of magnitude during the CVS cold start test procedure. Furthermore, the concentrations of CO and HC are particularly high during the first 80 sec. For this reason, catalytic emission control systems must be designed to operate with high efficiency, that means high reduction and conversion rates, as quickly as possible after the engine start-up. The catalysts should reach their operating temperatures within 20 sec, so that the emissions which are produced during the warm-up period of the engine can be controlled as quickly as possible.

To do this, further methods for improving the warm-up characteristics of dual-bed systems should be investigated.

One method which promises success is a thermal reactor acting as a "preheater" for improving catalytic converter performance. The thermal reactor is located at the cylinder heads. When starting with a rich fuel/air mixture, oxidation of carbon monoxide and hydrocarbons after adding air, ensures rapid warm-up of the

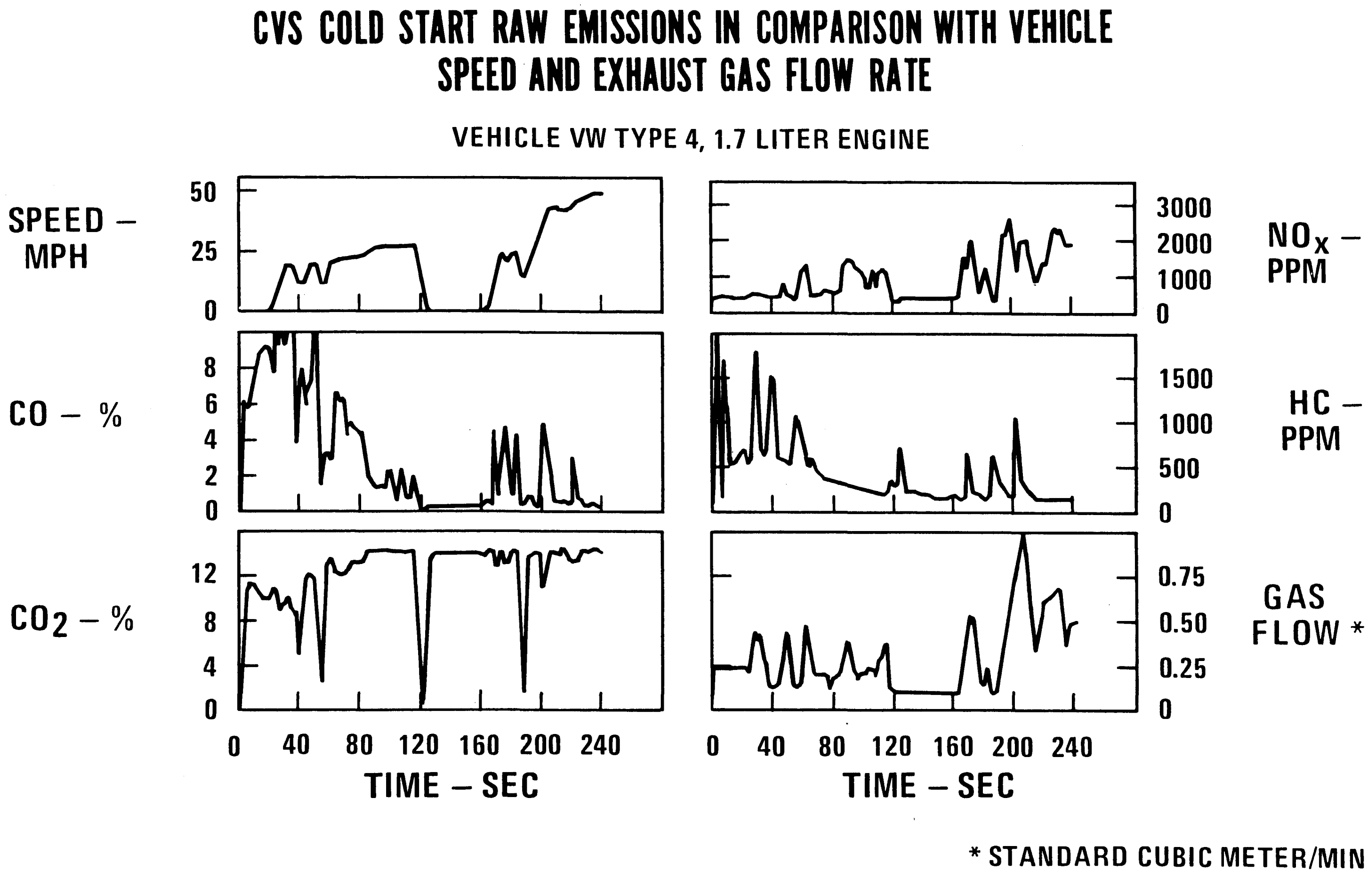

Figure 3

catalyst. In this system, secondary air is introduced in front of the thermal reactor at the cylinder head, and the reduction catalyst works as an oxidation catalyst in the starting phase. Due to the burning of high HC and CO emission levels directly after start-up a rapid warm-up of the after burning system and therefore a rapid attainment of operating temperature is ensured.

A catalytic reduction of NO_x is not necessary during the cold start phase because the engine operating temperature during this period is not high enough to produce very high NO_x emissions. After the catalysts in both beds have reached their operating temperatures (100-120 sec. after CVS cold start-up), the thermal reactor must be switched off. This is brought about by the transfer of secondary air introduction to the connecting manifold between the first and second catalyst beds.

Figure 4 illustrates a catalytic emission control system together with major hardware components which has been developed for research purposes. It consists of a monolithic dual-bed converter, series connected thermal reactor, by-pass system, exhaust gas recirculation (EGR), EGR cooler, regulating valve, and EGR filter. The efficiency of such an emission control concept can be improved by the introduction of an additional ignition system in the thermal reactor. By enrichment of the air/fuel mixture, an improvement can be obtained as can be seen in Figure 5. With 10% rich fuel/air mixtures (A/F = 13.0), the exhaust gas temperature at the thermal reactor outlet reaches 300°C five to six seconds earlier than with normal mixture strength (A/F = 16.0).

This high exhaust gas temperature increases the reactor warm-up rate, too. This means that the catalysts also reach their operating temperatures of about 300°C at least five seconds earlier.

Another method of improving the warm-up rate of the catalytic system with series connected thermal reactors is to cause an ignition failure of a single cylinder charge (which contains approx. 20,000 ppm HC) and at the same time to increase the idling speed of the engine together with wide open throttle. The technique produces an increased flow rate of exhaust gases with high unburned components during the cold start phase; the chemical energy of which can be converted into high exhaust enthalpy. This comparatively rich fuel/air mixture can be ignited in the reactor by an additional sparkplug. With an automatic control device, the ignition failure of a particular cylinder can be controlled in accordance with the firing order. After the exhaust gas has attained the operating temperature required by the catalysts the ignition system will revert to normal.

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