IMPACT OF FUEL CHARACTERISTICS ON IN-USE PERFORMANCE OF EXHAUST CATALYSTS

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ABSTRACT
In order to improve air quality, California has implemented a plan requiring low emission vehicles with advanced technology exhaust catalyst systems. These vehicles are certified and intended to operate on an advanced reformulated gasoline (California Phase 2). Other states have or intend to adopt a similar vehicle program, but although these vehicles will also be certified and designed for operation on the California Phase 2 gasoline, they will in practice be operated on a variety of gasolines, both reformulated and unreformulated. In some regions, enhanced inspection/maintenance tests will periodically be required which includes a test of the exhaust emission control system using a transient driving schedule. These tests will be performed using available commercial fuels, thus we have undertaken a study to determine the impact of several individual fuel properties on the resulting emissions produced during such a test. Properties varied individually include distillation, oxygenate content and sulfur level. In addition, the impact of each variable was measured at several different test temperatures to gain insight on the effect of ambient temperature on in-use emissions. We will discuss the result of these impacts and possible explanations based on additional insight gained from modal (second-by-second) emissions data as well as catalyst temperatures logged during the tests.

INTRODUCTION
One of the requirements for improving air quality called for by the Clean Air Act Amendments of 1990 involves the improvement of current programs in which vehicles are inspected in-use for emissions compliance. The enhancement as proposed by the Environmental Protection Agency for many non-attainment and neighboring areas requires vehicle owners to pass an emissions test at either a centralized inspection station or a qualified repair-and-test facility station in order to obtain a permit to register their vehicle [1]. In addition to the emissions test, the fuel vapor recovery system on the vehicle must also be checked for system integrity, and the OBD-II system checked for an activated MIL and stored fault codes.

One of the enhanced inspection/maintenance tests supported by the EPA involves an exhaust emissions compliance test in which tailpipe emissions of hydrocarbon, carbon monoxide and oxides of nitrogen are measured while the vehicle is driven over a transient schedule for 239 seconds [1-3]. This test, called the IM240 (inspection/maintenance 240) requires a relatively sophisticated chassis dynamometer and emissions measurement bench and is best administered at a centralized facility. It is already being utilized in enhanced I/M programs in Arizona and Colorado, and is being implemented in states such as Wisconsin, Maryland and Connecticut. Although alternative I/M tests may be adopted by other states, we will use the IM240 as the focus of this study.

As stated earlier, we are particularly interested in varying some fuel characteristics and the ambient test temperature to determine the impact on the resulting emissions. Such tests serve to probe the variety of test conditions that can be anticipated for I/M tests performed in the 49 states outside California, and allow us to compare such tests to those that would more closely represent conditions anticipated within California, recognizing that California has adopted a strictly controlled low-sulfur reformulated fuel to be sold state-wide [4]. This may be particularly important for Low Emission Vehicles which may be held to strict emission standards, even in in-use tests. Although these vehicles were originally proposed by California as part of their state plan to achieve better air quality, member states of the Ozone Transport Region (13 Northeast states and the District of Columbia) have or are in the process of considering adoption of the California Low Emission Vehicle program to meet their state implementation plan (SIP) requirements, without also adopting the California Reformulated Fuel Program.

For this study, then, we compare IM240 tests performed using a pre-production Transitional Low Emission Vehicle under relatively moderate temperatures using low-sulfur-content California reformulated phase 2 fuel to similar tests performed under a range of temperatures and using federal fuel surrogates with various distillation, oxygenate and sulfur content properties.

EXPERIMENTAL

The vehicle used for the enhanced inspection maintenance testing was a 2.2 L OHV Corsica equipped with a 4-speed automatic transmission and linear EGR. The vehicle was configured as a production-intent 1996 MY California TLEV and included a complete OBD-II system. The inlet of the single underfloor converter used with this vehicle is located approximately 50" from the exhaust manifold, and the converter itself is 110 cubic inches in volume, containing 2 oval cross section monoliths of the same size. The forward monolith contained a palladium technology washcoat, while the rear contained platinum and rhodium. A single converter was used for these tests and had accumulated 89,000 miles in customer service. This converter was evaluated for FTP performance using certification fuel on this vehicle with the following results: 0.089 g/mi THC, 2.28 g/mi CO and 0.32 g/mi NOx (all values comply with TLEV standards).

The vehicle was also configured with a converter inlet tap for modal engine-out emissions measurements. In addition, several locations in the exhaust stream and in the converter monolith beds were instrumented with thermocouples for monitoring the temperature at those locations. A portable laptop computer equipped with a serial port and an analog/digital conversion board was used to log selected engine operation and temperature data in real time during the IM240 test schedule.

The reference fuel used for this study conformed to the California Phase II reformulated gasoline standards, and contained sulfur at a level of 32 ppm. A relatively high vapor pressure fuel used as Wintertime surrogate contained sulfur at a higher level (485 ppm) and was used both with and without oxygenate modifications. A lower vapor pressure fuel used as a Summertime surrogate also contained sulfur at a higher level (480 ppm) and was also used with and without oxygenate modifications. MTBE was used in any oxygenate modifications. A summary of the fuel properties is listed in Table 1.

IM240 tests described in this study were conducted using a single 48" dynamometer roller which was electrically-loaded. This test site was capable of collecting both bag (integrated) and modal (second-by-second) emissions data, and is located in an environmental cell capable of test temperatures between -9°C and 36°C. Testing at low temperature with the high volatility Winter fuel simulates an IM240 test that would be encountered in much of the U.S. (outside of California) in the Wintertime. In practice the IM240 test may be run in a heated/closed bay; however, the vehicle will be exposed to cold temperatures during the urban driving phase and time at idle, and may also encounter these conditions during the exhaust test itself. Since the climate in the highly populated areas of California is moderate for the entire year, testing at ambient temperature with the strictly controlled California reformulated fuel simulates a California IM240 test for a majority of the state and for most of the year. Whenever fuels were changed in these tests, a purge procedure was followed to allow the vehicle sufficient exposure to the new fuel prior to conducting tests.

The IM240 emission tests were conducted using a procedure described in a previous publication [5] and was used to simulate typical customer driving history prior to an I/M test and to obtain highly repeatable results. This procedure generally included a soak period followed by an urban driving phase (bag II of the FTP), followed by an idle for 15 minutes, and finally the IM240 test (the 15 min waiting period for an IM test is considered to be representative of a typical wait time in the field [6]). For the purpose of this discussion we will focus on the modal emissions data generated during the IM240 portion of this study. Following the IM240 test, the vehicle was left to soak at the test temperature for at least 1 h with the fan directed into the radiator, and the entire test procedure (FTP Bag 2 + idle + IM240) could then be repeated. This entire procedure was repeated to produce two complete IM240 measurements for each fuel and time at idle matrix element.

RESULTS AND DISCUSSION

The first set of IM240 tests were run using the California Phase 2 reformulated fuel at 74°F (23°C). We found that the engine-out FTP emissions of 1.7 g/mi HC, 8.9 g/mi CO and 1.9 g/mi NOx were relatively consistent with the engine-out IM240 emissions of 1.3 g/mi HC, 9.2 g/mi CO and 2.7 g/mi NOx. The relative agreement in the engine-out emissions values provides further support for the IM240 test procedure as a relatively rapid surrogate for the FTP test. The tailpipe emissions performance on the IM240 was the following: 0.119 g/mi THC, 1.633 g/mi CO and 0.384 g/mi NOx, which also compare favorably with the FTP results at 0.089 g/mi THC, 2.28 g/mi CO and 0.32 g/mi NOx. In this case, the IM240 results were 34% greater for THC, 40% greater for CO and 20% greater for NOx when compared to an FTP test result. As will become apparent later, the IM240 results were consistently larger than the corresponding value obtained during an FTP test.

Our discussion will now turn to IM240 test conditions that can be commonly expected when Wintertime oxygenated fuel is available, typically November to March. In this study we ran IM240 tests at 20°F (-7°C), 40°F (4°C) and 60°F (16°C) to cover a wide range of ambient temperatures that can be expected for most of the country during the Winter. Although the numerical results are not reported here, the engine-out emissions obtained for these tests at the three temperatures mentioned above generally remained the same for all test temperatures and was similar to the results obtained using the California reformulated fuel, with the exception of NOx, which increased by roughly 45% as the temperature was decreased to -7°C from 16°C. The tailpipe emissions, however, are clearly impacted by both fuel property and test temperature. For example, test results obtained using the federal fuel at 16°C are between 40 and 100% greater (88% for HC, 85% for CO and 45% for NOx) when compared to test results using the California fuel at 20°C. Tailpipe emissions continue to increase dramatically with further decreases in test temperature, even with the same federal fuel being used for the tests. At -7°C, the tailpipe emissions levels are between 200% and 300% greater than the results obtained using California fuel at a test temperature of 20°C (specifically, 275% for HC, 275% for CO and 230% for NOx). Although the observed increase in the tailpipe emissions for NOx can be partly attributable to an increase in engine-out NOx levels under colder test conditions, most of the observed increase in HC, CO and NOx tailpipe emissions can be attributable to differences in the fuel properties and test conditions. As will be suggested by the following results, fuel oxygenate can influence tailpipe emissions, but not at all temperatures. At the lowest temperature used in this study (-7°C), tailpipe emissions are affected more by sulfur content and distillation.

A similar set of IM240 tests were also performed at 20°F (-7°C), 40°F (4°C) and 60°F (16°C) using the same fuel base, but with no oxygenate present. Tests using this fuel also resulted in increased tailpipe emissions when compared to tests using the California Phase 2 Reformulated fuel, and the increases were generally similar when compared with the oxygenated Wintertime fuel, except that CO was affected more and NOx was affected less with the non-oxygenated fuel at test temperatures above -7°C. Tests using this fuel at 16°C, for example, produced 0.205 g/mi HC, 4.38 g/mi CO and 0.401 g/mi NOx. This represents increases of 88% for HC, 150% for CO and ~0% for NOx when compared to the California fuel. Further decreases in test temperature to -7°C did result in further increases in tailpipe emissions, reaching 0.392 g/mi HC, 6.55 g/mi CO and 1.37 g/mi NOx, which represents increases of 260% for HC, 273% for CO and 230% for NOx. At moderate test temperatures of 16°C and 4°C, then, the addition of oxygenate to the fuel does reduce CO emissions as demonstrated in prior published studies. At -7°C, however, the presence of oxygenate in the fuel has no influence on the tailpipe emissions. A summary of the tailpipe results for both types of higher vapor pressure fuels are shown in Figure 1.

The observed IM240 tailpipe emission increases attributable to fuel and test condition effects are in good agreement with our previously reported study [5] of IM240 tests in which a similar test comparison was made between tests using commercial Winter fuel and California Phase 2 fuel using a similar TLEV. These results are in contrast to the typically cited 10-20% in-use emissions increases predicted by MOBIL5a to account for differences in the fuel properties, the latter forming the basis for the most stringent IM240 cutpoint tables. As mentioned above, although the increase in the tailpipe emissions for NOx can be partly attributable to an increase in engine-out NOx levels under colder test conditions, most of the observed increase in HC, CO and NOx tailpipe emissions can be attributable to factors which directly influence catalytic converter performance. It turns out that such factors are not related to converter temperature, since this was found to be similar regardless of the test fuel or test temperature, but rather to a combination of the influence of sulfur, operating air/fuel ratio, and HC composition and combustion characteristics of the fuel on converter efficiency as suggested by the modal data. A thorough discussion of these impacts is beyond the scope of this paper, but will be discussed more completely in a future paper.

Similar tests were conducted using a lower vapor pressure fuel to represent a summertime blend, but with an elevated sulfur (475 ppm) level. Tests were conducted both with and without oxygenate (~11% MTBE), and at test temperatures of 20°C, 16°C, and 4°C (the fuel drivability was poor at -7°C, thus tests were not run at that temperature). We found that in general, use of this fuel did not affect engine-out emissions when compared to the California Reformulated fuel (except that NOx was increased by 20% at 4°C, similar to the Wintertime fuel), but increases in the tailpipe emissions were observed. These increases, however, were not as significant as with the Wintertime fuel for the same test temperature. For example, tests at 16°C resulted in increases of ~30% for HC, 55% for CO, and 25% for NOx when compared to similar tests at 20° using the California fuel. Further decreases in test temperature did result in further increases in tailpipe emissions, but these increases were not as significant as with the Wintertime fuel. When a similar set of tests were run with the oxygenated version of this fuel, a similar trend was observed in that the tailpipe emissions increased with decreasing test temperature. However, the magnitude of the increase was smaller than observed for the non-oxygenated version of this fuel for a given test temperature. In summary, then, of the four federal fuel surrogates used in these tests, the highest tailpipe emissions were generally observed for vehicle operation at relatively low temperature (-7°C) using the high vapor pressure (or Wintertime) fuel blend with oxygenate present. The lowest tailpipe emissions were observed for vehicle operation at relatively moderate (~20°C) temperature using a lower vapor pressure fuel (Summertime) with oxygenate present. For comparison, the California phase 2 reformulated fuel produced even lower tailpipe emissions when tested under a moderate temperature condition. As we have mentioned previously, modal data indicates that the large observed difference in the tailpipe emissions (particularly hydrocarbon) when comparing low vapor pressure fuel tested at moderate temperature with high vapor pressure fuel tested at relatively low temperature can be attributed primarily to effects of the operating air/fuel ratio and the fuel hydrocarbon composition and combustion characteristics on converter efficiency. Colder test conditions lead to poorer air/fuel control, while higher vapor pressure fuels contain a larger relative percentage of relatively unreactive short-chained saturated hydrocarbons, part of which escapes combustion in the engine and/or oxidation in the catalyst. The presence of higher sulfur levels appears to accentuate these effects.

SUMMARY

We have investigated the effects of several fuel properties and test temperatures on the IM240 tailpipe emissions performance of a 1996 Corsica TLEV. We found that in all cases, the lowest emissions were obtained using a California phase 2 reformulated gasoline in tests at 20°C, while tests using federal fuel surrogates all produced higher tailpipe emissions, and the highest emissions were produced when high vapor pressure fuels were used under relatively cold temperatures (-7°C). In the latter case, the tailpipe emissions were between 200% and 300% greater than similar tests run using the California fuel at 20°C. The large increase in the emissions observed when tests were run on the federal fuels can be attributable to a combination of higher sulfur levels, lower test temperature, and different fuel hydrocarbon makeup (indicated by high vs. low vapor pressure).

REFERENCES

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Table 1.
Summary of Selected Properties of Test Fuels

Fuel Description	Vapor Pressure (psi)	Oxygenate (% vol.MTBE)	Sulfur (ppm)	Saturates/Olefins/Aromatics (%)
California Phase 2	6.6	11.1	29	73 / 5 / 22
federal fuel (high vapor pressure)	11.8	*	480	71 / 7 / 22
federal fuel (low vapor pressure)	7.9	*	475	74 / 4 / 22

* Each of these fuels were used with no MTBE added and with 11.5% vol. MTBE added.

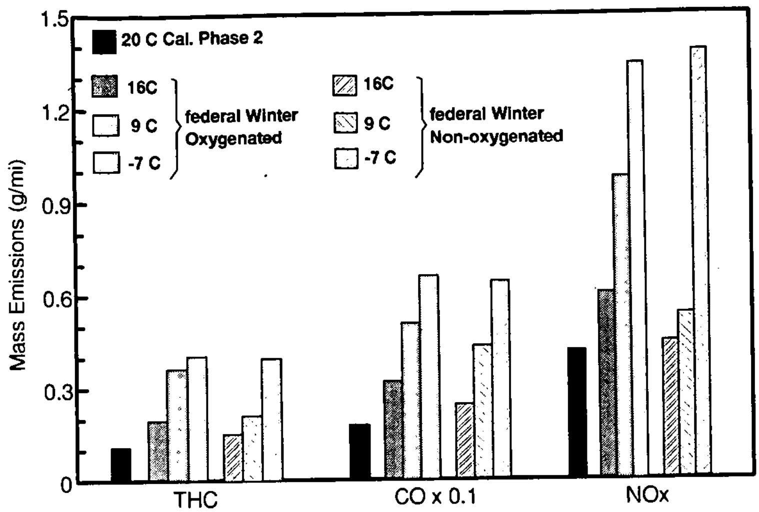

Figure 1. Comparison of IM240 tailpipe emissions at various test temperatures and for operation on different fuels.