

Oil Consumption Sources in a Modern Gasoline Engine Including Contribution of Blow-by Separator and Turbocharger: An Experimental Study Based on the Use of Radiotracers

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ABSTRACT

Minimizing engine oil consumption of modern engines has become an important issue and there is a need for better understanding associated sources and mechanisms. An innovative method based on the use of radiotracer compounds that are representative of oil distillation interval has been presented in a previous paper. This paper presents a methodology to evaluate and quantify oil consumption sources in a production turbocharged spark ignition engine at different speed and load conditions. A specific experimental set-up was used to measure independently and in real-time contribution of piston ring package, blow-by circuit, and turbocharger on oil consumption. Results show how contribution of each consumption source varies with engine operating conditions.

INTRODUCTION

New environmental regulations oblige engine manufacturers to optimize combustion processes, to reduce friction losses and to equip vehicles with sophisticated after-treatment systems. At the same time, petroleum companies still work actively on the development of new lubricants that are compatible with new materials, or coatings that can reduce engine oil consumption and have a minimal impact on long-term performance of after-treatment systems [1]. It has been previously established that oil consumption has a non negligible impact on particulate emissions [2], and oil evaporation is assumed to contribute significantly to the oil consumption from the piston-ring-liner system, especially during severe operating conditions when thermal loading of engine components is high [3]. Other studies [4] aimed at separating contribution of turbochargers in engine oil

consumption using conventional weighing methods. This study uses modern tools based on use of radiotracing techniques to determine oil consumption sources in a turbocharged gasoline engine. Applied methodology allowed reducing significantly tests durations due to its high sensitivity. It is based on the use of germanium-69 (Ge-69), a radio-isotope that substitutes carbon atoms in base oil molecules. This made it possible for real-time oil consumption measurement. Moreover, various oil fractions can be labeled with the radiotracer to make it representative of the oil distillation interval [5]. During our study this radiotracer method has been adapted to separate and quantify sources of oil consumption. The paper focuses on an experimental set-up that allowed measuring independently contribution of piston ring package, blow-by circuit, and turbocharger.

METHODOLOGY

The method used during this experimental study is based on the use of organic radiotracers [5]. Germanium-69 (Ge-69) was used to label various types of lubricants. Labeled molecules are base oil molecules where one carbon is replaced by Ge-69, which is a gamma ray emitter. This radiation allows monitoring and quantifying accumulation of oil molecules anywhere in the engine (pipes, intercooler...). This also applies for oil burned in the combustion chambers since an absolute filter is installed in the exhaust line (Fig. 1).

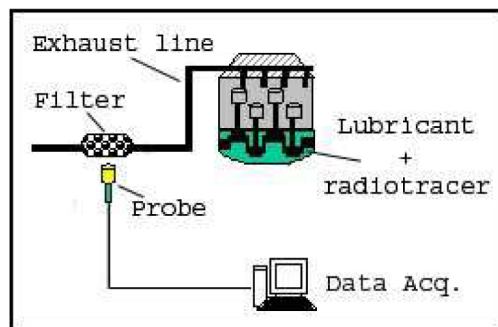


Fig. 1. Radiotracing method for on-line oil consumption measurement in the exhaust line

During engine operation, labeled oil residues accumulate into this filter and a radiation probe installed nearby monitors the signal emitted by oil residues that accumulate in the filter (cumulative measurement). This signal is converted in terms of oil consumption in g/h after a calibration procedure is applied, which is described hereafter.

SELECTED ENGINE AND LUBRICANT

The selected engine is a modern gasoline turbocharged MPI with the following characteristics: 4 cylinders in-line; 2L displacement; turbocharged; 16 valves; max. output power 132 kW; torque 300 Nm from 2.250 rpm. It has been installed on a 280 kW dyno, a tandem machine that combines a 200 kW Eddy Current brake and a 80 kW electrical machine. Fig. 2 shows the experimental set-up with both oil consumption and fuel dilution monitoring devices. A standard oil grade was selected: 5W30 with a viscosity around 12.3 cSt at 100°C and a Noack volatility around 11%.



Fig. 2. Engine installed on test bed with oil consumption measurement in the exhaust line (front left) and fuel dilution monitoring device (front right)

PRELIMINARY TESTS (FUEL DILUTION MAP)

In the past we have frequently observed that fuel dilution should not always be considered as a negligible process when gasoline engines are operated in severe conditions. This applies for both direct and indirect injection gasoline engines. Fuel dilution has an impact on oil viscosity and, therefore, it may also affect oil consumption. Fuel dilution can also affect seriously oil consumption measurement results when the weighing method is applied since the mass of diluted fuel is taken into account. Our campaign was started with a 20-hour running-in phase since the engine was new. Then, a fuel dilution map has been carried out. Another radiotracer method has been applied [6]. It consists in adding the same radiotracer (Ge-69) into the engine oil. Specific radioactivity of the lubricant (the number of gamma rays emitted for a given mass of oil) is monitored in a chamber where engine oil is circulated during engine operation. Variations of specific radioactivity are correlated to the dilution rates. Results of this fuel dilution map are presented in Fig. 3. We can observe that dilution rates (DR) increase with speed and load. DR is in the range of 1% at full load, with a maximum of 1.43% per hour measured at 4.000/100%. Oil and coolant temperatures were regulated at standard values during this test, with 100°C for oil and 90°C for coolant.

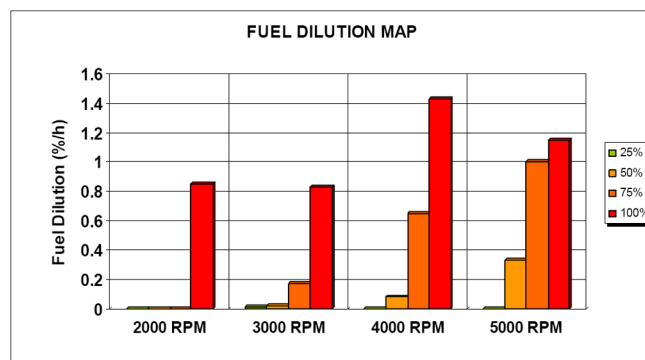


Fig. 3. Fuel dilution map (in % volume) - quantity of fuel accumulating in oil per operating hour (volume), at 25%, 50%, 75% and 100% load

From our experience, dilution is inevitable but it has a very little impact on oil consumption results as long as it does not exceed ~2% in volume. Engine tests presented in this paper have been performed in such a way that fuel dilution never exceeds 1.5% at the end of tests. This was not really a critical issue since test duration for measuring oil consumption was in the range of 15 min. only for the severe operating point. Situation would be totally different if the weighing method was applied since test duration would be of 20 hours at least per operating point.

EXPERIMENTAL SET-UP

After this preliminary work, a separated lubrication circuit has been installed into the test cell for lubricating the turbocharger (TC) independently (Fig. 4) from the engine. This separate lubrication unit has been especially developed for this application. It works in such a way that oil pressure in the TC circuit exactly reflects the original oil pressure produced by the oil pump of the engine: a pressure probe measures in real time oil pressure in the gallery and a PID unit corrects automatically pressure in the TC with a response time of 0.2 sec. Oil temperature is also automatically adjusted to a preset value (100°C). This set-up with separated TC lubrication system allowed injecting the radiotracer either in the TC oil circuit or in the engine sump. It allowed measuring oil consumption from the TC independently from the rest of the engine. Two oil consumption probes have been installed in the vicinity of the engine: one in the exhaust line, nearby an absolute filter that was used to trap all radiotracer residues issuing from combustion chambers and/or from the TC turbine. The other probe was situated downstream the blow-by gas separator. It consists of a very efficient filter made of activated charcoal - its efficiency is known to vary between 96 to 98% for blow-by flows from 1 to 60 L/min. -combined to a radiation probe that monitors accumulation of labeled oil in the filter. The two measuring probes performed cumulative measurements: they monitor the increase of gamma ray signal associated to accumulation of oil or oil residues. Measuring probes were calibrated in order to obtain oil consumption results directly expressed in grams per hour. Additional hardware was used to also measure independently blow-by rates generated by the engine block and by the TC.

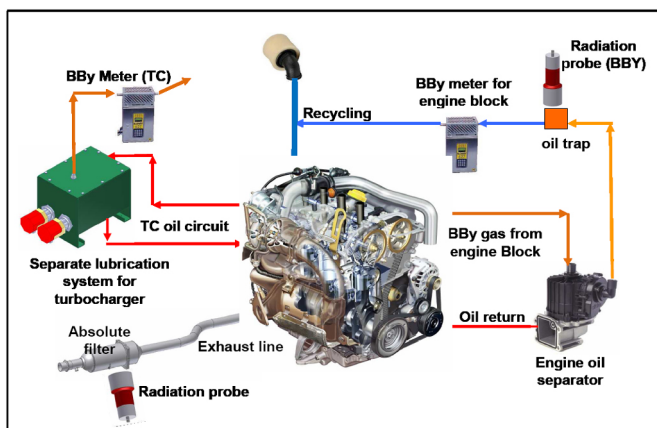


Fig. 4. Hardware set-up with independent lubrication system for the turbocharger

During engine tests, the following parameters were monitored and recorded: engine speed (rpm) and load (Nm), exhaust manifold temperature (°C), exhaust filter temperature (°C), air temperature (°C), engine coolant temperature (°C), oil temperature (°C), fuel temperature (°C) and blow-by rates (L/min) for the engine block and for the TC. Only results

showing a good stability of the above parameters were taken into account. Engine performance curves have also been acquired every day to check the “health” of the engine.

Absolute calibration of engine oil consumption

The following procedure has been applied to determine oil consumption of the engine block, which was lubricated separately from the TC: a well known quantity of labeled oil (a few grams) is taken from the engine sump at the end of tests. This oil sample is weighted accurately and it is added to approximately 5 liters of fuel. The mixture (fuel + oil sample) is burned in the combustion chambers after engine has been drained and flushed with fresh oil (no tracer). Response of the probe (increase of gamma ray signal) installed in the exhaust line corresponds to the consumption of the oil sample added to the fuel. Oil consumption of the engine is not taken into account during this measurement since radiotracer has been removed during oil drain. Therefore, a direct correlation is made between the increase of signal of the radiation probe and the mass of labeled oil burned in the combustion chambers.

OIL CONSUMPTION SOURCES: ENGINE BLOCK

During this first series of tests the radiotracer is injected into the engine sump. No radiotracer is added to the separate oil circuit that lubricates the TC. A few milliliters of Ge-69 labeled oil are added to the oil. The selected radiotracer organic compound is representative of a medium fraction in the distillation interval (boiling point of ~420°C). Homogenization of the mixture requires a few minutes of engine operation. The above described experimental set-up allowed measuring simultaneously and independently oil consumption associated to the engine block and oil consumption downstream the blow-by gas separator. One probe installed in the exhaust line monitors oil consumption from the engine block only (piston ring package + valve seats). Another probe monitors oil consumption through the oil separator. As the filter installed after the separator offers an excellent efficiency (>98% for BBY rates lower than 60 L/min.) one can consider that blow-by gases are free of oil when re-aspirated through the compressor stage. This means that oil residues that flow into the exhaust line come exclusively from the engine block (oil consumption through piston package and valve seats only). Fig. 5 shows the oil consumption map obtained with the probe installed in the exhaust line.