OIL CONSUMPTION MEASUREMENT OF A HEAVY DUTY DIESEL ENGINE

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ABSTRACT

Lubricant oil consumption measurement of internal combustion engines is getting great importance due to stringent emission regulations, development process, and customer satisfaction. However, accurate and fast measurement of oil consumption is very complicated task. Over the years, different techniques including conventional methods, tracer methods and analytical prediction methods have been developed. Conventional methods are based on mass or volume measurement of lube oil before and after a long engine running under defined conditions. Although these methods are easy to operate, require long periods of engine running and provide low accuracy results. Other experimental technique is tracer methods that include the measurement of tracer material in the exhaust gas due to consumed oil. These methods are complicated but results are very fast and precise. Moreover, real time oil consumption measurement is possible. Analytical prediction methods present idea about oil consumption in short time via using some assumptions and estimations. In order to achieve fast and accurate oil consumption, sulfur (S) tracer method was used in this study. Therefore, high S content lubricant oil and low S content fuel was used on a heavy-duty diesel engine. A quadrupol mass spectrometer was employed to analyze the sulfur dioxide (SO_2) concentration of the exhaust gas in real time. Engine mapping of oil consumption of a heavy-duty diesel engine over speed and load was executed and experimental results were compared with AVL Glide analysis, which is a theoretical oil consumption prediction program.

1. INTRODUCTION

1.1 Motivation

Lubricating oil consumption is one of the primary interests for the automotive industry due to stringent emission regulations and customer satisfaction. Moreover, lube oil consumption points out the troubles with the engine functionality during the development process and assists in improvement of features.

The most significant issue for oil consumption is increasing concern about environmental pollution and stringent emissions standards. Background

1.1.1 Oil Consumption Sources and Mechanisms of IC Engines

The primary investigation to understand the lube oil consumption in modern internal combustion engines is describing the oil consumption sources. These sources consist of piston-ring-liner system, crankcase ventilation system, valve stem seals and turbocharger as illustrated in Figure 1 schematically.

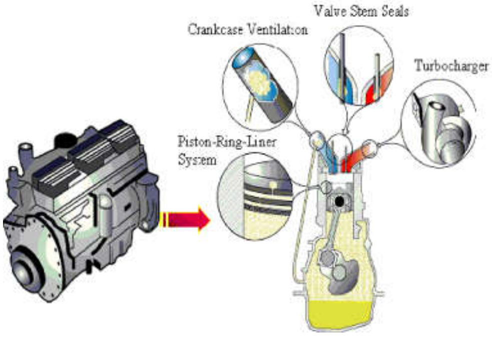

Figure 1: Oil Consumption Sources

Since the oil consumption mechanisms of these sources are so complicated, it is difficult to understand completely. The first one was “oil rising” which was related to transportation of oil into the combustion chamber and the second one was “oil disappearing” which described the burned and unburned oil in the exhaust gas.

Moreover, that two main experimentally verified directions of oil consumption. These directions were due to valve train and path via the cylinder. In addition, they underlined that oil consumption through the piston cylinder system was dominant contributor when compared to oil loss through the valve train.

Oil consumption sources including piston-ring-liner system, turbocharger, and valve guide leakage are specified below.

1.2 Objective

The background and literature survey above showed that lube oil consumption is very important problem due to stringent emission regulations, engine functionality, and customer satisfaction. It is clear that an accurate, fast, repeatable, and efficient means of measuring oil consumption is required to aid the manufacturer in controlling the amount of engine oil consumption. The review of literature clearly indicated that other researchers had successfully measured oil consumption by S tracer method. Therefore, this study began with an assumed hypothesis that oil consumption can be accurately measured by S tracer method under appropriate conditions.

The objective of this paper is to develop an experimental method to determine the oil consumption of a 9 liter heavy-duty diesel engine in real-time based on S tracer method. For detection of SO_2 in the exhaust gas, a mass spectrometer (MS), which is a combination of chemical ionization (CI) and quadrupol mass spectrometry, has been adapted. In order to calculate the amount of oil consumption, chemical mass balance has been applied. Moreover, with the aim of verifying experimental results, test engine has been modeled using AVL Glide lube oil consumption module.

2. Evaporation from the Liner Wall

The loss of oil remaining on the liner wall as a wafer-thin film is defined by mass transfer over the phase boundary in the medium of combustion gas with certain gas turbulence. Figure 4.2 shows the oil surface which is exposed to the hot combustion gas.

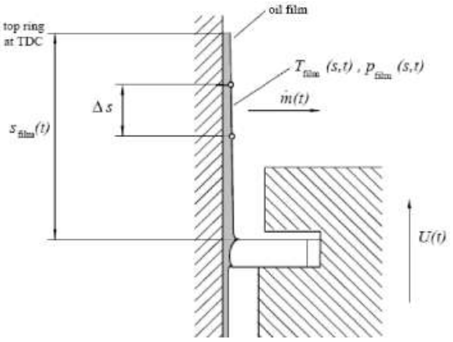

Figure 2 : Oil Mass Flux into Combustion Gas

The oil is either carried away with the gas or is burned at sufficiently high gas temperatures. The steady state convective mass transfer applied to simulate the evaporation rate is given in Equation 2.

$$\beta \cdot (C_{film} - C_\infty) = \dot{m} = -D \cdot dc / dy$$

Where

β = Material transmission coefficient

C_{film} = Concentration of lube oil at film surface

C_∞ = Concentration of lube oil in combustion chamber

$\dot{m}$ = Mass flow through boundary surface (=liner surface)

D = Diffusion coefficient

y = Coordinate perpendicular to boundary surface

Δs = Movement of the piston during time step Δt

S_{film} = Uncovered area of the oil film

2.1 Oil Throw-off

The flow balance of lube oil over the first piston ring and the consideration of the piston acceleration enable the calculation of the thrown-off oil quantity. The current oil volume above the top ring and the acceleration of the piston determines the possible thrown-off oil quantity.

The following oil transport mechanisms leads to a decreasing or increasing of the accumulated oil at the top side of the first ring.

2.2 Oil Scraping of the Top Ring

The scraped amount of oil is determined by the difference of the left oil film thickness during the upward and the downward motion of the top ring.

Oil Flow through the Gap into the 1st Inter Ring Area

Due to a positive pressure gradient oil accumulated above the first ring will flow down the gap into the 1st interring area. The oil flow due to a negative pressure gradient into the combustion chamber is assumed as instantaneous loss of the oil.

Oil Flow at Ring and Groove Flanks

The squeezed oil causes the oil flow from the area behind the ring to the area above the ring, if the ring moves relative to the piston and by the flow due to the pressure gradient.

The sum of this particular oil flow leads to a surge wave between the piston top land and the liner wall. The evaluation of throw-off is given by net flow of oil upwards to the combustion chamber. The entire surge wave is divided into discrete layers as shown in Figure 3. For each layer, a constant acceleration is assumed.

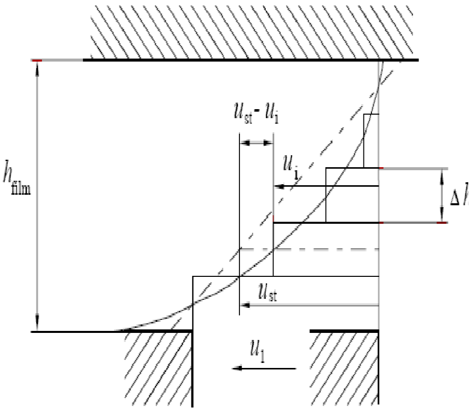

Figure 3: Layer Model for Oil Throw-off

The amount of throw off is given by Equation 1.

$$Vthrow\text{-}\ off- \quad = (Um - U_{s\ t\ \mathrm{m}}) \cdot h\ film \cdot d\ film \cdot \pi \cdot \Delta t$$

Where

$um = \sum U_i / i$ Mean instationary velocity

$U_{St,m=}a_o \cdot \Delta t / 2$ = Mean stationary velocity

$Um - U\ st\ m,$ = Mean difference velocity of the oil film

a_0 = Acceleration at the beginning of motion

$h_f ilm$ = Height of the oil film between top land and liner

$d_f ilm$ = Diameter at oil film

Δt = Time step

Oil Blow through Top Ring End Gap

The pressure gradient over the top ring allows computing the oil blow through the end gap into the combustion chamber.

In case on a negative pressure gradient over the top ring (combustion pressure < pressure at 1st interring area) oil is blown through the end gap. The oil quantity due this effect is assumed as an instantaneous oil loss and is not exposed the inertia forces.

Oil Scrapping of the Top Land Edge

The scraped amount of oil, illustrated in Figure 4, is calculated by considering the piston's lateral movement and tilting motion together with geometric conditions.

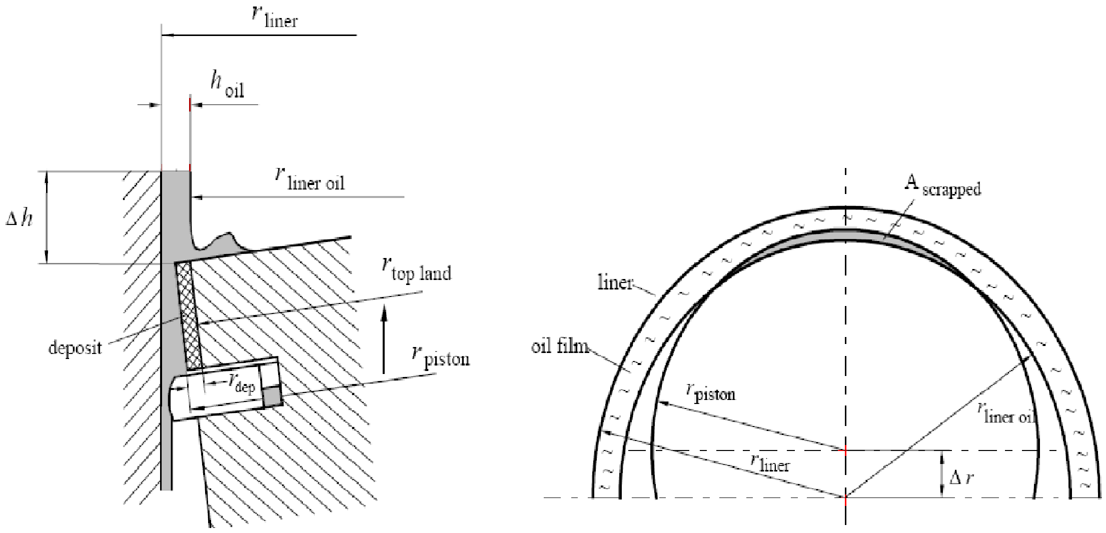

Figure 4: Oil Scraping of the Top Land Edge

The scrapped volume during the axial piston movement is given by Equation 4:

$$V scrapped = A scrapped \cdot \Delta s$$

Where

$A_{scrapped}$ = Oil scrapped area
Δs = Axial piston movement

2.3 Analysis Result

Four different engine operating points (2200 rpm, 1600 rpm, 1300 rpm at their full load and idle speed) have been modeled. The used engine parameters are presented in Appendix E. Since the thermal load is the maximum during the combustion period, oil consumption rate increased due to evaporation which is the main contributor. For instance, instantaneous oil consumption with respect to crank angle at 2200 rpm and 100% load, consumption curve made a peak between 20 and 25 crank angle region due to combustion chamber temperature, as seen in Figure 5.

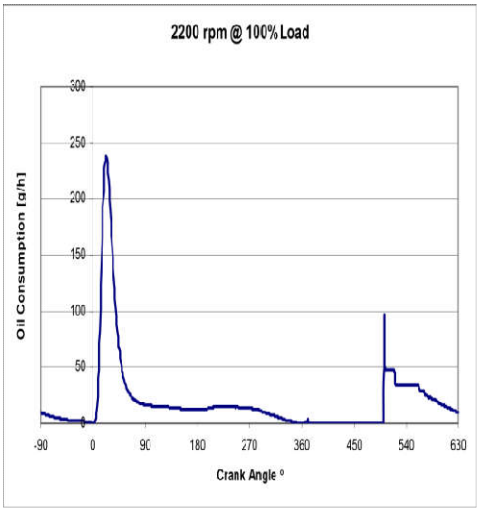

Figure 5: Instantaneous Oil Consumption at 2200 rpm 100% Load

2.4 Comparison of the Experimental Results and the Analysis Results

Instantaneous AVL Glide analysis result was integrated over crank angle and total oil consumption rate calculated for four different engine condition described above. As seen in Figure 5, analyzed oil consumption results showed same tendency with experimental results. Oil consumption rate in g/h increased as the engine speed increased.

Additionally, comparison of experimental results and analysis results are illustrated in Figure 6. The analysis results were proportional to experimental measurement results. On the other hand, the reason of difference between two oil consumption results were that, analysis results did not cover the contribution of turbocharger, valve stem seal and crankcase ventilation to total oil consumption. Since the AVL Glide analyzed only piston-ring-liner system, results were lower than experimental results based on S tracer method.

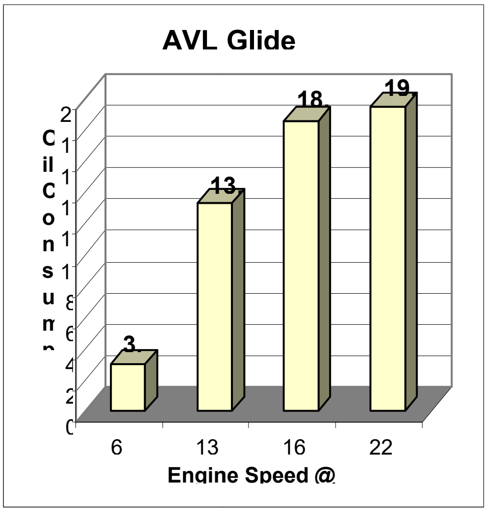

Figure 6: AVL Glide Oil Consumption Analysis Results

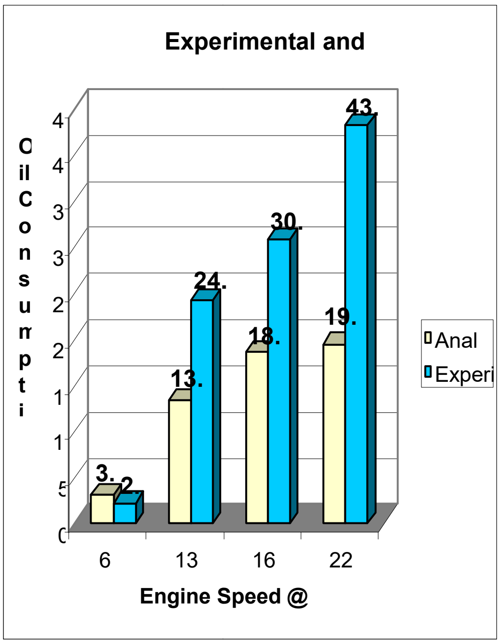

Figure 7: Comparison of Experimental and Analysis Results

3. CONCLUSION AND FUTURE WORK RECOMMENDATION

Controlling the lube oil consumption of internal combustion engine is important meeting stringent emission regulation standards, engine functionality, and customer satisfaction. With this purpose, accurate, fast, repeatable, and efficient means of measuring oil consumption is required. Although, conventional methods are still used by engine manufacturers, more reliable oil consumption measurement is a necessity in order to optimize the oil consumption. Consequently, tracer methods are the best solution for accurate and real time oil consumption measurement while they enable determining the oil consumption of an internal combustion engine over load and speed within acceptable action period. S tracer method is one of several tracer methods designed to measure S found in the engine exhaust.

The purpose of this study was to develop an experimental method to determine the oil consumption of a 9 liter heavy-duty diesel engine in real time. Therefore, a real time oil consumption measurement test system based on S tracer method using mass spectrometer was developed. For this purpose, the instrumentation required for the system has been assembled and using low S content fuel and relatively high S content lubricating oil, the measurement system was demonstrated.

Several months of time and work were devoted to the study of the instrumentation measurement techniques and trouble shooting. Then, a newly designed heavy-duty diesel engine was tested by S tracer method to determine oil consumption characteristic. Among the measurements, an oil consumption map over engine load and speed was prepared. The highest oil consumption rate was 43.29 g/h at 2200 rpm full load operating point. Moreover, oil consumption tendency was increasing with load and speed.

The test engine was a prototype which does not have the actual calibration and design of a serial production engine. Therefore, the measured results do not represent the lube oil consumption of the 9 liter heavy-duty diesel engine which is currently in development.

Apart from engine mapping, test engine was also modeled in AVL Glide lube oil consumption module. The analysis results were proportional to experimental measurement results while analysis result covered only oil consumption due to piston-ring-liner system.

In the future, the measurements should be continued and test procedure should also be developed and optimized in order to obtain perfect data in the shortest operation period. A new lubricating oil formulation is supposed to be used in the tests in order to ensure if S is equally distributed in the oil and S concentration of lubricating oil remains same during the test period.

Moreover, the test system capabilities can be developed in order to determine oil consumption contribution of turbocharger and crank case ventilation. It is also possible to measure oil consumption of individual cylinders of the engine with some construction modifying on the exhaust manifold.

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