

Development of a Lube Filter with Controlled Additive Release for Modern Heavy Duty Diesel Engines Utilizing EGR

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ABSTRACT

As on-highway heavy-duty diesel engine designs have evolved to meet tighter emission regulations, the crankcase environment for heavy-duty engine lubricants has become more challenging. The introduction of Exhaust Gas Recirculation (EGR) has allowed for significant reductions of exhaust emissions, but has led to increased oxidation and acid build-up in the lubricant. Engine lubricant quality is important to help ensure engine durability, engine performance, and reduce maintenance downtime. Increased acidity and oxidation accelerate the rate at which the lubricant quality is degraded and hence shorten its' useful life. This paper explores the use of a lube filter with a controlled additive release to maintain lubricant quality.

INTRODUCTION

Since the late 1980's, diesel engine emission legislation has been a primary driver for the evolution of heavy duty diesel engine design. Optimization of the combustion process and the use of EGR have significantly reduced exhaust emissions, but have increased the demands on the crankcase lubricant. In order to maintain crankcase lubricant quality, the American Petroleum Institute (API) has released a new heavy-duty engine lubricant category for use with each new U.S. heavy-duty, on highway emission specification. The most recent category, CJ-4, is tied to the emission specification that went into effect in 2007.

The ability of a heavy-duty diesel engine lubricant to provide acceptable wear protection over its service life is dependant on many factors. Among them are lubricant quality, engine design, severity of duty cycle, and fuel sulfur level. In general, the use of revised combustion schemes, including the use of EGR, to meet exhaust emission requirements has increased the demand on the lubricant in three main areas. The first area is increased soot loading of the lubricant. Soot loading can lead to viscosity increase, due to soot agglomeration, which can cause filter plugging and cold flow issues. High levels of soot can also contribute to increased engine wear, primarily at the boundary lubrication zones of an engine (1). To accommodate the increased soot loading of the oil, dispersant and anti-wear additives have been utilized. Both the Mack T11 (5) and Cummins ISM dynamometer (dyno) tests evaluate a lubricants performance related to soot loading and are required for CJ-4 certification (2). The second area is higher lubricant sump temperatures. Higher sump temperatures increase the rate at which the lubricant is oxidized. Oxidation can lead to bearing corrosion due to the creation of weak acids, carbon deposits, and sludge. To impede oxidation of the lubricant, antioxidant (AO) additives are utilized. The third area is increased acid introduction into the lubricant. Sulfuric, nitric, and organic acids are all introduced into the engine lubricant and can cause corrosion of engine components such as cylinder liners, bearings, and piston rings. To neutralize acids in the lubricant, and prevent engine component corrosion, over based detergent (OBD) additives are used (3). The Mack T12 (6) dyno test evaluates a lubricants ability to minimize cylinder liner, piston ring, and bearing wear due to acids and oxidation of the lubricant and is required for CJ-4 certification (4).

This paper provides an overview of the development of a lube filter with a controlled additive release. The theory relating to the additive release mechanism and lab testing to confirm the theory and filter design are presented. Engine dyno and field test data are also presented demonstrating the effectiveness of the filter to maintain lubricant quality.

THEORY

The cause for developing a lube filter with a controlled additive release is based on the theory that by introducing the proper formulation and quantity of additive(s) at a controlled rate, the useful life of oil can be increased. In order to provide a controlled additive release, a simple yet functional release mechanism is required. The additive release mechanism that was developed is based on two main principals. The first is related to stagnation pressure which is utilized to force the additive out of its reservoir. Stagnation pressure is generated by the flow of oil through the oil filter and is determined by Bernoulli's theorem:

$$z_1\rho + P_1 + \frac{\rho V_1^2}{2} = z_2\rho + P_2 + \frac{\rho V_2^2}{2}$$

Where:

z = elevation above reference level

ρ = fluid density

V = mean velocity of flow

P = pressure

Simplified for stagnation pressure ($z_1=z_2$ and $V_2=0$) it is written as:

$$P_2 - P_1 = \frac{\rho V_1^2}{2}$$

Where:

$P_2 - P_1 = \Delta P$ = stagnation pressure

The second principal relies on the use of a metering tube to control the release rate of the additive which is determined by Darcy's formula:

$$Q = \frac{\Delta P d^4}{\mu L}$$

Where:

Q = rate of flow (additive release rate)

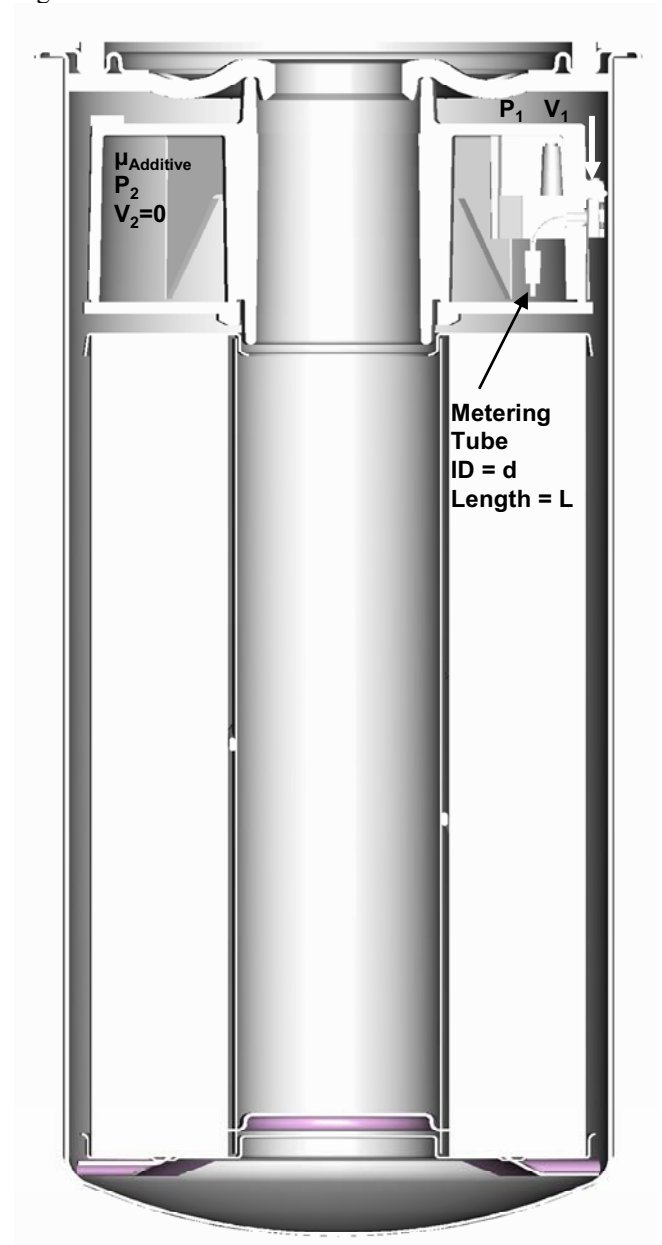
ΔP = pressure differential across tube (stagnation pressure)

d = internal diameter of metering tube

μ = absolute (dynamic) viscosity

L = length of metering tube

Figure 1 – Additive filter schematic



FILTER DESIGN

Using the principals described in the previous section, the filter design can be tuned to achieve the release rate of additive as required. The design controllable inputs include the metering tube internal diameter, clearance area at the stagnation port, initial additive viscosity, and metering tube length. Darcy's formula shows the strong influence of the metering tube internal diameter on the release rate due to its exponential power of four. Note that the clearance area at the stagnation port will determine the flow velocity at that location for a given flow rate through the filter. The engine inputs which influence the release rate include the engine speed and lubricant temperature. The engine speed is related

to the oil flow rate through the filter and hence the flow velocity at the stagnation port. The lubricant temperature at the filter will influence the viscosity of the additive during operation. Although engine speed and temperature are not constant over a trucks duty cycle they do remain within known boundaries under normal operating conditions. Figure 2 shows the relationship between engine speed and oil flow for a typical heavy duty truck engine. Figure 3 shows the relationship between the additive viscosity and temperature.

Figure 2 – Lubricant flow rate vs. engine speed

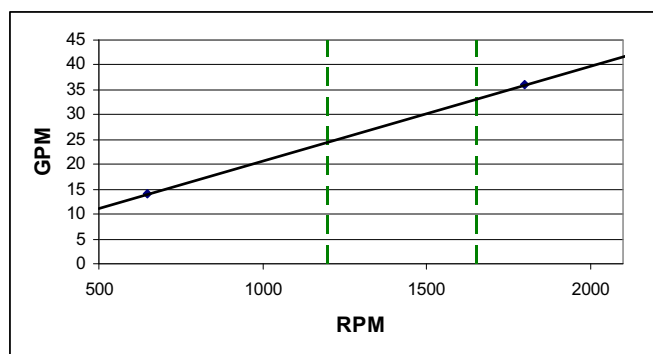
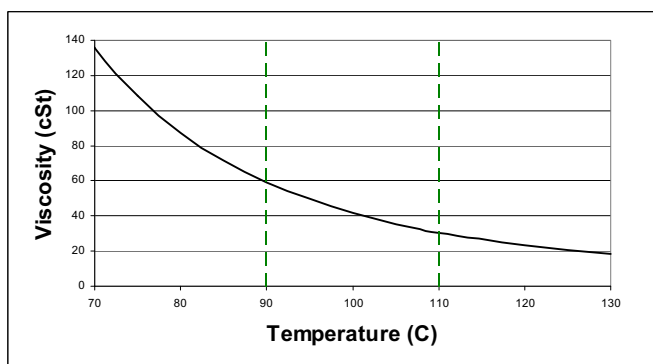


Figure 3 – Additive viscosity vs. temperature

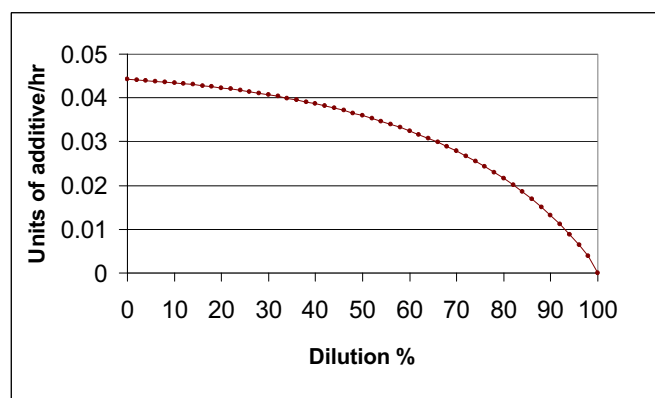


Although the additive release rate will increase with higher engine speed and oil temperature, and visa versa, it is directionally advantageous. This is due to the fact that typically higher engine speeds correlate to higher road speed and faster mileage accumulation (oil change intervals on over-the-road trucks are normally based on mileage) and at higher oil temperatures there is a greater need for the additive to help counter oxidation.

One other factor studied was the potential impact of additive dilution on the release rate of the additive. Dilution is a potential concern due to the fact that the additive released from the additive housing is displaced by sump oil. This allows a volume of sump oil equivalent to the amount of additive released to co-occupy the same volume and the potential for diffusion to occur between the two. Although there is very limited mixing energy available inside the

additive housing to drive a high diffusion rate, diffusion occurs and must be taken into consideration. Figure 4 represents how the additive release rate is affected at various levels of dilution. Note that the decay is not linear. This is because the incoming sump oil is lower in viscosity than that of new additive. Thus, any additive dilution also leads to a decrease in additive viscosity which acts to counter the dilution effect by providing a higher flow rate through the metering tube. Even with this countering effect, a significant reduction in additive release rate occurs at dilution values of 80% and greater. This suggests that the total volume of additive used should be at least 20% greater than that based on a release model assuming no dilution to assure an acceptable additive release rate is maintained into the oil drain cycle.

Figure 4 – Dilution effects on additive release rate



LABORATORY VALIDATION

To prove the controlled release additive filter concept, three key aspects had to be studied and validated. The first aspect was the additive release mechanism. To accomplish this, a flow stand was utilized. The flow stand allowed the additive filter to be tested at various flow rates and sump temperatures. Because the volume and composition of the lubricant used in the sump was known and the volume and composition of additive in the additive housing was known, the additive release could be monitored using elemental analysis by ICP. Figure 5 shows the results from one of the flow tests conducted where two filters were flow tested with steady flow at 93 C and 99 C. The dotted line in the figure represents the predicted release rate based on the transfer function and the solid line represents actual results. Note that the higher temperature run, as predicted, releases at an increased rate. This test also demonstrated that the oil soluble plug, used to seal the additive housing until placed in service, also released successfully.