Oil loss mechanisms due to in-cylinder components

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ABSTRACT

Oil loss in internal combustion engines has been a concern for a long time. With the advances in manufacturing technologies and an improved understanding of engine tribology the oil loss in automotive applications has been continuously reduced. Increased awareness regarding environmental pollution and tightened regulations necessitates the study of oil loss to emissions. Oil transport inside the cylinder is also intimately linked to piston and ring performance, friction loss and blowby. Therefore, an understanding of oil loss and the relevant oil transport characteristics is imperative for improved component and engine design. Due to the complex nature of oil transport mechanisms and a lack of experimental investigation of underlying individual physical phenomena, modeling efforts have so far been limited compared to other in-cylinder issues such as ring and piston dynamics and blowby.

This paper summarizes the known and conceptualized oil loss mechanisms believed to contribute to engine oil loss through in-cylinder components.

Key-words: oil loss, oil transport, IC engines

INTRODUCTION

Oil transport to the cylinder and pistons has important implications in internal combustion engines. The availability of lubricating oil affects the piston and ring performance, blowby and friction power loss generated in the cylinder due to the moving pistons and rings.

The exhaust gases are formed predominantly due to the combustion of fuel, however, engine oil transferred into the combustion chamber also contributes to some of the exhaust products. As the hydrocarbon emissions originating from gasoline and diesel fuel are progressively reduced with improved engine and converter design, small amounts of lubricating oil composed of heavier hydrocarbons contribute significantly to hydrocarbon emissions.

Experiments have shown the oil loss in engines to be through two primary routes. The valve train is known to account for 25-30% of oil loss, whereas the remaining 70-75% of oil loss is attributed to loss in the cylinder. The mechanism of oil transport through the valve train is comparatively simpler to analyze. On the other hand, understanding the physics of the transport of oil through the crankcase-cylinder route has been difficult. This is partially due to the difficulty of carrying out controlled experiments that reveal the relationship between various design parameters and oil transport. Although the general effects of ring and piston design on oil loss are well known by engine manufacturers, the underlying physical mechanisms are not well understood. This has limited the modeling efforts to phenomena perceived to be important in oil transport.

IN-CYLINDER PHENOMENA

The inherent difficulties in analysing the complex dynamics, lubrication, gas flow and heat transfer phenomena occurring within the cylinder have forced an experimental approach to design and development of the in-cylinder components. This has resulted in an accumulation of know-how in engine manufacturers. Although engine and component manufacturers have a through understanding of the overall effect of design parameters on component performance and reflect this on component development, intricacies and details of the basic phenomena are not always well understood.

Beginning in 1950's researchers started applying advanced analytical and numerical techniques for the analysis of in-cylinder phenomena.

Today, numerous models are available for the analysis of piston and ring dynamics, pin-bearing lubrication, piston lubrication and deformation, ring lubrication and blowby in integrated and stand-alone models. All these analyses have varied levels of sophistication and most of them model the underlying physics accurately. Two of the in-cylinder phenomena, namely the representation and quantification of the dynamics of the oil film on the liner and the transport of oil from the crankcase to the combustion chamber remain the most eluding.

The analysis of the ring radial motion is rendered complex due to the coupling with the ring face lubrication. The oil left on the cylinder is entrained under the oil ring and later left behind on the cylinder again. The presence of an oil-gas interface on the advancing and retreating oil film coupled with the accumulation of oil on the leading edge of the ring results in a complex fluid flow – lubrication – dynamics problem. So far no formulation of the problem in literature exists that accounts for all the above phenomena, including the effect of surface tension.

The ring face lubrication is intimately related to the transport of oil by the motion of the piston and the rings. This is only one of the many complicating factors in the analysis of oil loss.

OIL LOSS MECHANISMS

Three mechanisms are believed to be important in the transport of oil through the cylinder route. These are:

i) Oil left on the cylinder surface and mixed with the combustion chamber contents due to evaporation. This is later consumed during the combustion process.
ii) Oil mixed with the blowby gases and transported back to the combustion chamber when the combustion chamber pressure drops at the beginning of exhaust. Some of the oil sucked to the combustion chamber may flow out of the exhaust valve before the valve closes. This would show up as unburned hydrocarbons at the exhaust.
iii) Oil accumulated by the top compression ring due to the scraping of oil film on the cylinder. This may be left on the cylinder eventually or thrown into the combustion chamber due to the deceleration during the upstroke.

EVAPORATION OIL LOSS - The evaporation oil loss has been modelled by Wahiduzzaman et.al., and shown to account for approximately 5-10% of known oil consumption in diesel engines. One important result is that the thickness of the oil film left on the cylinder plays a minor role in the amount of oil evaporated. This is due to the fact that the thickness of oil on the cylinder - in the range of 1-10μm – does not affect the heat transfer between the cylinder surface and combustion chamber gases, therefore, plays a minor role in the rate of evaporation. The more important factor is the temperature of the cylinder block. With increasing cylinder temperatures the oil loss due to evaporation also increases. It should be noted that the amount of oil left on the cylinder surface during one downstroke is many orders of magnitude larger than the known oil consumption in current engines. Only a film in the order of magnitude of molecular thicknesses of oil smeared on the cylinder is lost to evaporation.

BLOWBACK OIL LOSS - The blowback of oil into the combustion chamber with gases is physically well founded. Experimental verification and the flow paths have been documented by Nakashima et. al.. (1996). The are a number of difficulties in modeling this mechanism. Engine oil is entrained into the blowby gases passing through the ring end gaps and deposited in the inter-ring cavities. When the pressure in the combustion chamber drops below the inter-ring pressures, a backflow of blowby gases starts. This results in the oil backflow to the combustion chamber. During part of this backflow, the exhaust valve is still open. This results in part of the entrained oil to directly move to the exhaust pipe as unburned hydrocarbons. As far as the hydrocarbon emissions is concerned this is the most likely cause of engine oil contribution.

There are two sources for oil entrainment into the blowby gases. The first one is the oil that flows under the rings and left on the cylinder. The thickness of the oil film can be measured and a lubrication analysis of the ring face could also be used for modeling the phenomenon. The second possible source is the oil accumulated on the top of the rings due to the scraping effect during the upstroke (and on the bottom surfaces durign the sownstroke).

In addition to the difficulties in experimentation, modeling efforts are hampered because of the following reasons:

i) Presence of a two-phase (gas-liquid) flow, where the liquid film thickness is very small. The problem is highly 3-dimensional and the interaction between the gas and liquid at the interface is complex.

ii) The pressure ratios across the compression rings are high. This results in high gas velocities and renders the flow in the short channel sonic. Therefore, compressibility effects are important, and velocity gradients are very steep.

iii) The modeling of entrainment of oil into the gas is complex. In conjunction with near sonic to sonic speeds, and the resulting dynamic effects, this phenomenon is affected by surface tension.

iv) The flow geometry can be perceived as two large reservoirs (two inter-ring volumes), connected by a short channel (the ring gap). But the thickness of the oil on the surfaces from which oil is to be entrained (i.e. the cylinder surface in the neighbourhood of the ring end gap, and the top surface of the ring) are not well known. Although there are measurements of oil thickness on the cylinder (Preston, 1999), no such data are available for the thickness of oil accumulate on the top of the ring, and ring grooves.

All the above difficulties need the adaptation of a progressive analysis to the problem. Once individual issues listed above are addressed, a comprehensive analysis of the complex physical problem can be sought. However, experimental guidance about the relative importance of the individual phenomena would help modeling efforts.

SCRAPING OIL LOSS - As the piston moves up towards the TDC, the top compression ring advances towards an oil film left behind by itself during the downstroke. The dynamics of the ring in the axial direction dictates the amount of oil to flow under the ring and left on the cylinder (Dursunkaya et.al. 1991). Similar analyses have been carried out by various authors (Yeng (1992) Gulwadi(1998), Tian et.al (1998)). Some simulations indicate that during the thermodynamic cycle, an accumulation of the oil at the top of the ring occurs. This accumulate is smeared back during the downstroke, but if the amount of accumulation is large, there is the possibility of the oil to be entrained into the blowby gases in large quantities. Depending on the size of the accumulate, oil may also be thrown inside the combustion chamber at TDC, where the inertia is largest due to the reversing cylinder motion.

Similar to the blowback oil loss, the scraping oil loss requires the analysis of a free surface phenomenon. In the event of a throw-off mechanism, the dynamics of the formation of oil jets or oil bubbles are equally difficult to model. There are no experiments in the literature to indicate the presence and/or importance of these perceived mechanisms.

CONCLUSION

As the US and European regulatory bodies dictate order of magnitude reductions in emissions, more effort will be spend to reduce emissions originating from engine oil. Although converter technology is likely to be the prime tool in the arsenal, improved piston and ring design may help addressing the problem. The mechanisms of oil transport, however, are an aggregation of numerous individual events, most of which are difficult to analyze, and even the validity of some of these mechanisms is in question.

On the other hand, the analysis of oil transport is of interested due to the intimate coupling with improved ring and piston performance and a reduction in blowby. Analysis tools developed in the past 15 years have significantly improved the understanding of ring and piston dynamics and lubrication, and a deeper understanding of oil transport will have a positive impact on friction reduction as well as enhanced component performance and design.

In order to model oil transport, all the individual physical mechanisms must be understood and handled. This would, however, result in the analysis of a number of mechanisms whose contribution to oil transport is questionable. A prudent approach would be a critical analysis of the importance of the proposed mechanisms followed by the verification of the comparative contribution thereof through experimental investigation prior to large scale modeling.

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