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Study of Impact of Engine and Vehicle Level Parameters for Reduction in Engine Oil Consumption for Advanced Emission Architecture Commercial Vehicles

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ABSTRACT

Automotive industry has seen implementation of advanced emission regulations like BS-VI in India along with growing market demand for increased product performance and reduction in total cost of ownership. This has made the engine architecture more intricate leading to complex interaction among engine and vehicle level parameters. This poses technical challenge for achieving critical product attributes like increased power density, higher fluid economy and reduced oil consumption (OC).

The current paper focusses on reducing engine oil consumption across diverse duty cycles using simulation tools, vehicle data analytics and test cell Design of Experiments (DOE). The contribution of oil consumption mechanisms viz. oil evaporation, oil throw and oil transport have been understood across different loads and duty cycles patterns. The critical parameters at engine and vehicle levels are identified affecting low load and high load oil consumption. Vehicle testing is conducted, and the real time data analytics was used to identify correlation of vehicle duty cycle parameters like percentageof Idling, Thermal Management Operation, Coolant Temperature, etc. with measured oil consumption. Piston ring dynamics simulation has been used to optimize critical ring parameters impacting oil consumption through directional trends. DOE was conducted in engine test cell environment to assess effect of critical parameters like combustion temperature and oil ring tension for high load oil consumption.

The new test cycles for verifying oil consumption at various loads are described. Results of interaction and main effects for individual factors are discussed. The parameters having weaker co-relations are also highlighted. The proposed solution is a combination of piston ring pack geometry features, thermal management calibration strategyand vehicle idling controls. The demonstration of final recipe of solution at vehicle level showed substantial improvement in oil consumption over baseline as well as over global industry benchmark. The improvement is demonstrated in the actual vehicle applications for mining tippers and tractors

KEYWORDS: Engine; Vehicle Level Parameters; Oil Consumption; Emission; Commercial Vehicles; Design of Experiments (DOE).

Introduction

India has leapfrogged to advanced BS-VI emission norms for auto industry from April 2020. The advancement in emission regulation is also accompanied by growing customer expectations and demand for superior commercial vehicle in terms of Higher power density, higher reliability, and lower total cost of ownership.

Engine Oil consumption has been one of the key aspects for reducing total cost of ownership for the customer by improving oil drain intervals and thus reducing the recurring maintenance cost.

Reducing the engine oil consumption is becoming critical requirement because the higher engine oil consumption as non-soluble organic fraction has negative impact on soot plugging of diesel particulate filter, DPF and the deterioration of SCR catalyst in the exhaust gas after-treatment device of diesel engines

Reduction in oil consumption is also driven by advanced after treatment architecture which needs oil with low ash contents to avoid effects like clogging of DPF filter and SCR catalyst deterioration[1,2,3]. Further higher engine oil consumption is perceived as poor quality of product by selective customers.

ABBREVIATIONS: OC – Oil Consumption; R&R – Repeatability and Reproducibility; TC – Transient Cycle; IAT – Intake Throttle Valve; SCRTM – Selective Catalyst Reduction Thermal Management; ETV – Exhaust Throttle Valve; LC – Loaded Cycle; ETT – Elevated Temperature Test; SCR – Selective Catalyst Reduction; ISD – Idling Shut Down Feature.

Oil consumption is studied over long period right since inception of diesel engine technology. It's a need of time to reinvestigate and develop insights into the internal mechanism due to increased complexity and interactions within the advanced emission architecture. As per literature, there are three dominant oil consumption mechanism viz. Oil Transport, Oil Evaporation, Oil Throw. The oil consumption is governed by dominant mechanism dictated by actual duty cycle operation. These oil consumption mechanisms are well elucidated in paper by Wood et. al along with dominant mechanism as function of engine load[4]. As explained in Fig. 1 oil transport is major dominant factor at low load operation whereas evaporation is dominant at high load operation[4]. To know exact contribution and underlying physics for given architecture, engineer needs deeper understanding of vehicle duty cycles, piston ring dynamics, thermal management interaction, combustion characteristics, internal air flow dynamics, oil dilution rate etc.

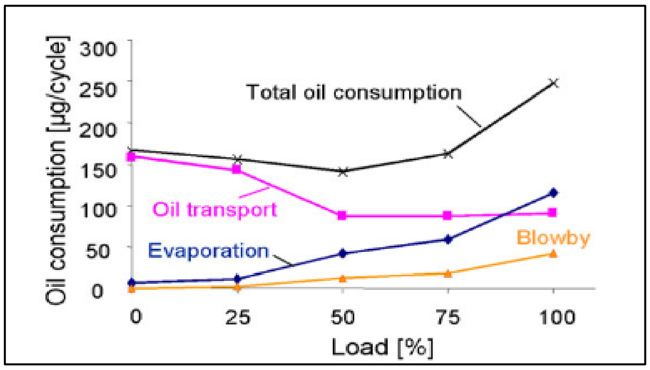

Fig. 1. Oil Consumption Mechanisms Across Varying Loads.

BS-VI architectures typically deploy Intake air throttle, Exhaust throttle valve for thermal management of after treatment system. These valves operate based on the strategy over Torque- Speed map to maintain the aftertreatment system temperature above a threshold to achieve desired emission conversion efficiency. For instance, SCR Thermal management map is activated based on the duty cycle operating point for achieving the desired NOx conversion efficiency. The very operation of these valves changes the internal flow dynamics, combustion temperature, intake manifold pressure, piston inter- ring pressure, blow-by etc. which directly impacts engine oil consumption. Thereby it becomes even more challenging to reduce oil consumption from existing global industry benchmark. Further the vehicle and duty cycle parameters like % Idling time or % time spent in Thermal Management mode plays crucial role in influencing total oil consumption over duty cycle.

The problem is more aggravated as OEM's typically use the same engine and combustion recipe for different applications and duty cycle. It's worth highlighting that devising an internal new test cycle is equally crucial for demonstrating design driven oil consumption improvements in the test cell as one to one correlation on the vehicle duty cycles.

Typical Oil consumption values ranges between 4 to 6 grams per standard cycle as per internal benchmark for diesel engines. The sections below describe the detailed approach used to significantly reduce the oil consumption from existing benchmark without impacting engine durability. The approach uses rigorous vehicle real data mining, physics based analytical and simulation tools, new test cycle development, Design of Experiments to arrive at right design changes and vehicle level controls.

Application Duty Cycles

The current work is focused primarily on Mining Tippers and Tractor applicationswhich has diverse duty cycle operations. As depicted in Fig.2, tractor-trailer duty cycle is characterized by high speed and high load operation. Whereas Tippers typically operates at low speed & low load region as shown in Fig.3. Fig.4 further helps to understand the difference in the acceleration & aerodynamic speed where tipper shows to have more transient characteristics than tractor-trailer. Formulas from Michael P. O'Keefe, et al[5] are referred to derive the duty cycle characterization of tractor & tipper application. The duty cycle data is crucial to understand dominant mechanism and identify critical parameters affecting oil consumption.

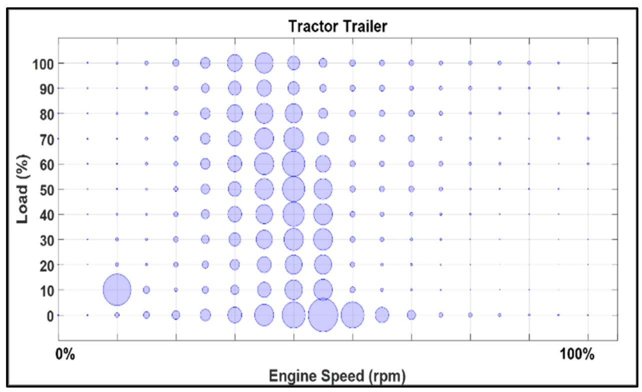

Fig. 2. Tractor Application Duty Cycle.

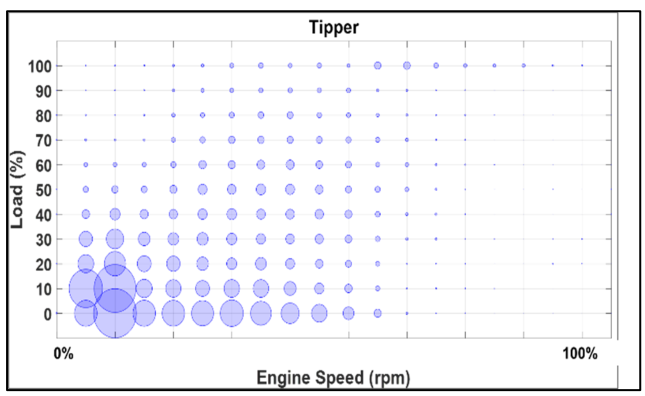

Fig. 3. Tipper Application Duty Cycle.

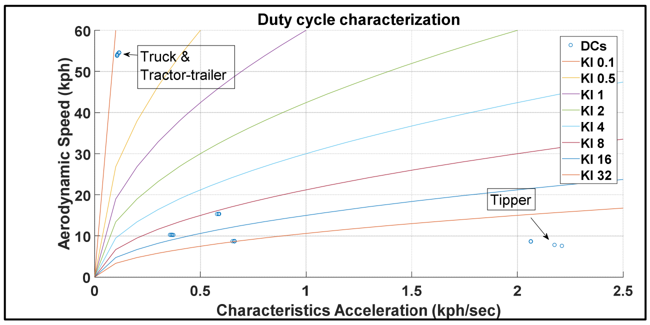

Fig. 4. Vehicle Duty Cycle Characterization

Critical Parameters for Oil Consumption

The approach begins with identifying the critical parameters affecting the oil consumption. Rigorous studies have been done related to reduction in oil consumption in the past and mainly focused on oil transport and oil evaporation which contributes about 70 to 90% of total oil consumption[4].

Oil volatility correlation has been studied with coolant outlet temperatures as well lower vicious oil on oil evaporation for different steady state engine speed and load conditions for spark ignition engine however focus was more on high load and higher engine speed study with respect to oil volatility[6,7]. Turbo charger and oil consumption downstream has been studied however oil consumption of the selected engine was found to be caused by the engine block i.e. piston ring pack + valve seats/valve metering rate[8].

The advanced emission architecture incorporates special devices like Intake Air Throttle (IAT) and Exhaust Throttle Valve (ETV) for thermal management of after treatment system. Growing demand of higher fuel economy push the engine to have combustion recipe with higher compression ratio[9]. The underlying physics thus becomes more complex to analyse the main and interaction effects among critical parameters. The critical parameters for engine system against the oil consumption mechanisms specific to BS-VI architecture are identified. Table 1 and Table 2 shows the critical parameters at engine and vehicle level respectively

TABLE 1

Engine Level OC Parameters.

Engine OC mechanism	Parameters
High Oil slobber	a) **low Idling slobber** b) **IAT operations** c) **intake manifold pressure** d) valve stem seal effectiveness
High Oil transport	1) **Ring Dynamics features** 2) **Transients operation** 3) Bore distortion
High Oil evaporation	A. **Gas/combustion Temp** B. Bore Surface Temp
High Oil leakage	1. Leakages through Air compressor 2. Oil carry over – Breather 3. Leakage through Other systems (Turbo, Oil cooler)
Measurement Uncertainty	a. Repeatability and Reproducibility b. **Fuel in oil**

TABLE 2

Vehicle Level OC Parameters.

Vehicle level	Parameters
Coupled OC Mechanisms	▪ **Intake manifold pressure** ▪ Charge temperature ▪ **Rate of change of torque** ▪ **Rate of change of speed** ▪ Coolant temperature ▪ **Percentage Idling** ▪ **Percentage SCR thermal management**

Based on the literature and subject matter inputs few parameters as highlighted in bold are chosen for detailed study. The correlation for critical parameters on vehicle and engine levels were developed and analysed in the following sections.

Effect of Vehicle Critical Parameters on Oil Consumption

The vehicles were identified, and pre-defined route was used to monitor data in real time. The oil consumption was measured every 200 hrs for tipper and every 10000 kms for tractors. Total of 5 Tipper application and 3 Truck and Tractor applications were equipped with data logger and monitored regularly to understand the underlying co-relations.

Table 3 shows the comparison of operating duty cycle parameters for Mining tippers and tractors. The tippers are operated in cyclic pattern with laden and unladen condition in a day. The tractors are driven on specified highway and back constituting a trip or cycle. The tippers run at low vehicle speed and spends significantly higher time in idle condition. This happens due to long continuous idle events spent between loading & unloading activities. The SCR thermal management operation is higher in tipper application. Subsequently, tractor runs at higher vehicle speeds and higher loads. Engine operates more at base calibration mode due to higher operating temperatures. The real time data is captured and analyzed to obtain correlation with oil consumption and explained in following sections.

TABLE 3

Comparison of Vehicle Duty Cycle Parameters for Tractor & Tipper.

Duty Cycle Operating Parameter	Tipper	Tractor
Trip Time	200 Hr	10000 km
Engine speed range (rpm)	600 to 1350	900 to 1550
Engine torque range (Nm)	0 to 340	0 to 800
Vehicle speed range (kmph)	3.4 to 9.4	26 to 64
Avg. charge pressure (kPa) +/- Std Dev	87.5 to 142.1	90 to 130
Avg. coolant temperature (DegC) +/- Std Dev	80 to 90	78 to 86
Idle time (%)	30.8	7.5
Time in Base Mode (%)	42.3	90
Time in SCRTM (%)	57.7	10

Idling Correlation

Idling of engine can directly influence oil consumption due to lower intake manifold pressure which influences ring dynamics and further oil slobber due to lower loads. To reduce the idling time, Idle shutdown feature was introduced through engine calibration (Cal) in the trials. Idle shutdown feature can shut down the engine when the vehicle is stationary and idles for pre-determined duration. Considerable improvement was observed for oil consumption for the tipper vehicles reduced from ~70 ml/cycle to ~60 ml/cycle after idling shut down (ISD) feature was implemented as shown in Fig. 5

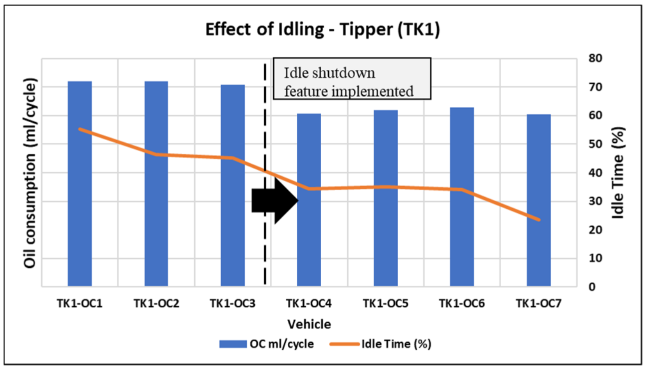

Fig. 5. Impact of Idling on Oil Consumption for Tipper Unit TK1.

Charge Pressure Correlation

The tipper duty cycle operates at low speed & low load causing lower intake manifold or charge pressure as seen in the Table 3. Fig. 6 shows charge pressure scatter plot for 1 Hz data over the entire vehicle operation in a cycle. The negative intake manifold gauge pressure was observed during the operation. The reason attributed for this is the operation of Intake air throttle operation needed for thermal management. The calibration was optimized to reduce the Intake air throttle operation in low loads condition. The thermal management calibration was tuned to improve the manifold pressure signature. Fig. 7 shows the improved scatter plot compared to Fig. 6. The oil consumption was reduced marginally with this change at vehicle level.

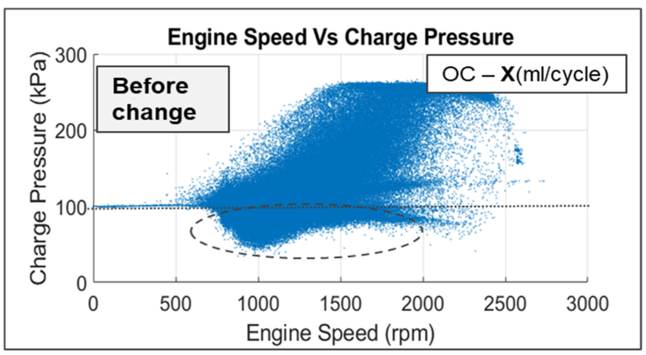

Fig. 6. Reduced Negative Charge Pressure with Final Calibration.

Co-relations with other vehicle operating parameters

The coolant temperature, charge temperature & SCR thermal management for multiple trials was inspected for correlation with oil consumption. Fig. 8\9\10\11\12 & 13 shows that no specific trend could be found between any of the parameters with oil consumption. Also, the transient effect of tipper duty cycle was evaluated by calculating rate of change of engine speed & engine torque. Figure 14\15\16 & 17 shows that no correlation between these parameters with oil consumption both, for tipper and tractor applications.

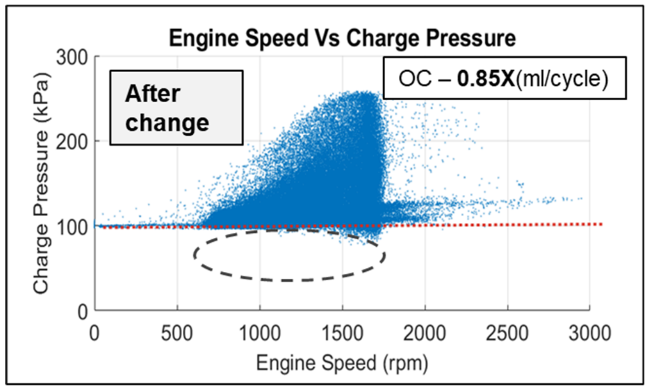

Fig. 7. Reduced Negative Charge Pressure with Final Calibration.

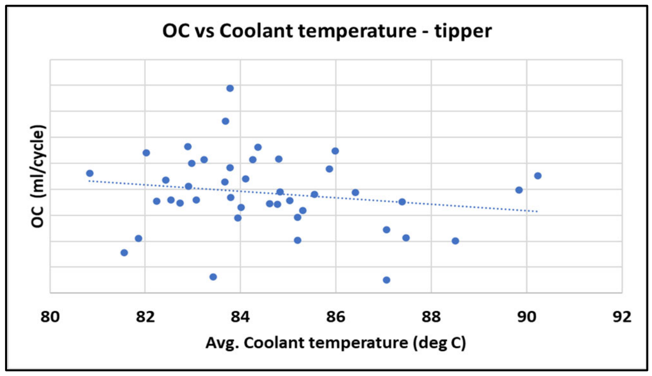

Fig. 8. Tipper Coolant Temperature & OC Trends.

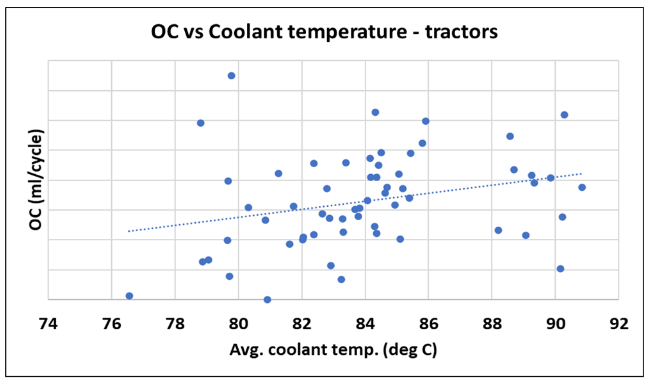

Fig. 9. Tractor Coolant Temperature & OC Trends.

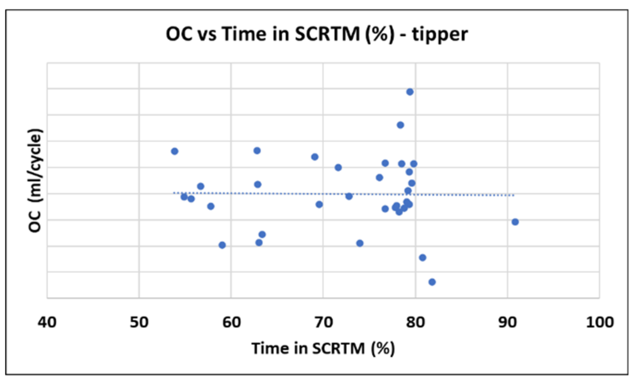

Fig. 10. Tipper SCRTM & OC Trends.

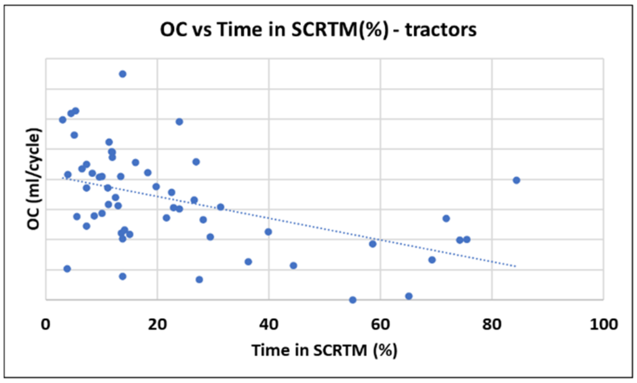

Fig. 11. Tractor SCRTM & OC Trends.

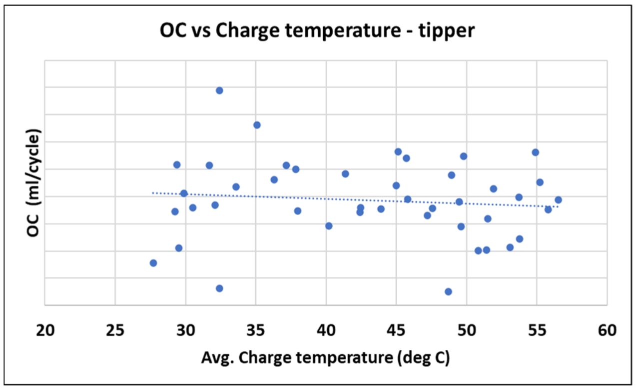

Fig. 12. Tipper Charge Temperature & OC Trends.

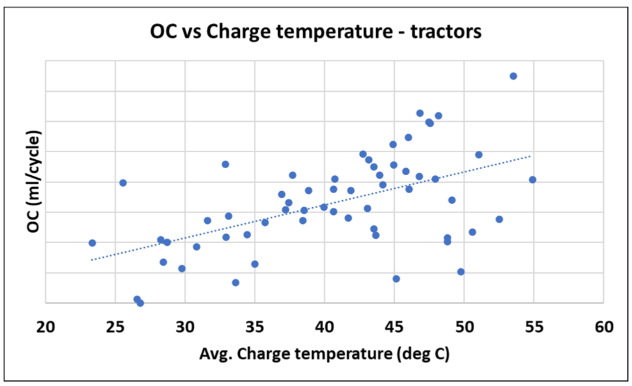

Fig. 13. Tractor Charge Temperature & OC Trends.

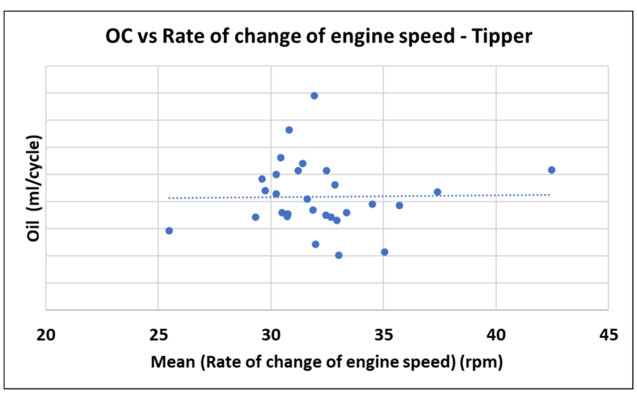

Fig. 14. Tipper Rate of Change of Engine Speed & OC Trends.

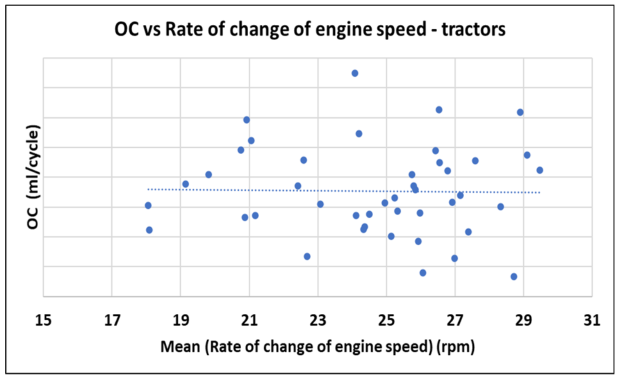

Fig. 15. Tractor Rate of Change of Engine Speed & OC Trends.

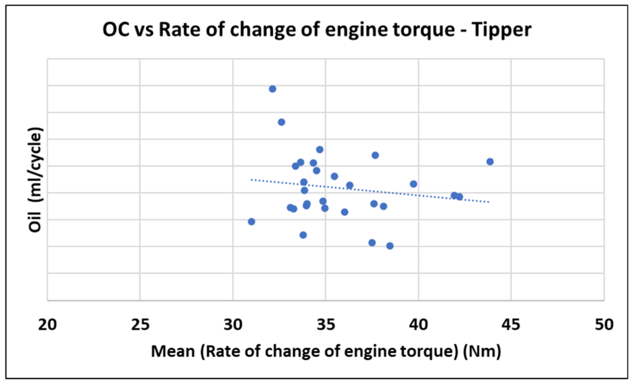

Fig. 16. Tipper Rate of Change of Engine Torque & OC Trends.

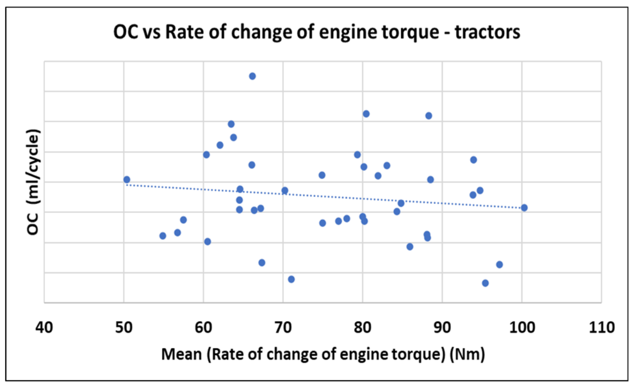

Fig. 17. Tractor Rate of Change of Engine Torque & OC Trends.

Piston Ring Pack Design and Optimization through Simulation

Fig. 18 shows the illustration of different oil consumption mechanisms viz Oil throw off, oil transport, oil entrainment, oil evaporation and leakage through valve stem seal.

Piston ring pack performance is typically optimized for rated power and maximum torque conditions. Simulation provides insights into to oil transport at Low load and low speed operating points. The simulation also enables to includes thermal management effect which changes the intake and exhaust pressures and affects the ring dynamic behaviour. Ring dynamic analysis using AVL excite simulation tool was used to understand the performance of the ring pack for key operating conditions. Ring dynamic simulation helps to understand oil transport, entrainment and throw off through prediction of ring movement and gas flow through the ring pack across engine thermodynamic cycle. Oil evaporation rate is also predicted roughly with certain assumptions.

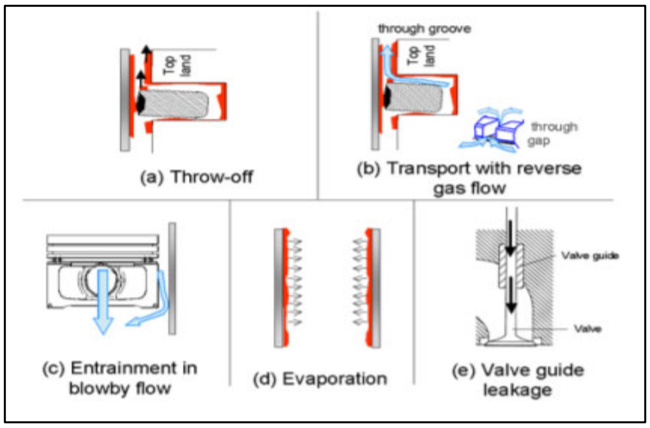

Fig. 18. Illustration of Inter-Ring Gas Pressure and Ring Motion.

This tool has a limited capability to predict the contribution of different oil consumption mechanisms accurately however can be used effectively to know the oil consumption qualitative trends.

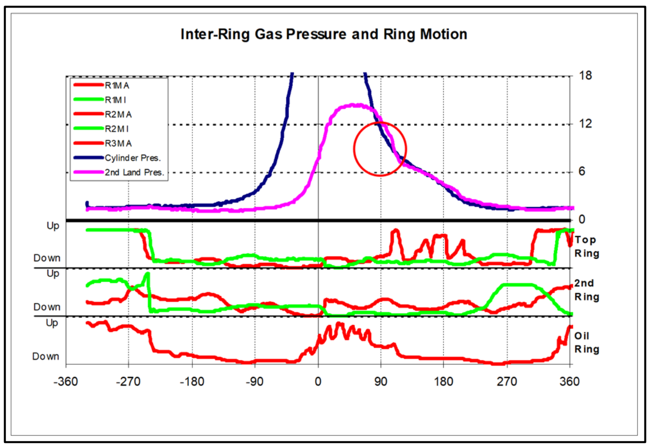

Fig. 19. Illustration of Gas Pressures Across Thermodynamic Cycle for Baseline Ring Pack.

Amongst all, the oil transport plays dominant role at low load operating point. The prediction of underlying physics involves complex interaction of inter ring gas dynamics and multi-phase flow past the piston rings.

Combustion pressure and inter ring gas pressure varies during the engine thermodynamic cycle which affects the ring motion as shown in Fig 19. If inter ring gas pressure exceeds the combustion pressure early in the power stroke, it results in reverse blow by.

Reverse blow by gases tend to carry oil with them into the combustion chamber leading to higher engine oil consumption as illustrated in Fig. 20. The crank angle at which combustion pressure and inter ring pressure equals is called as cross-over point.

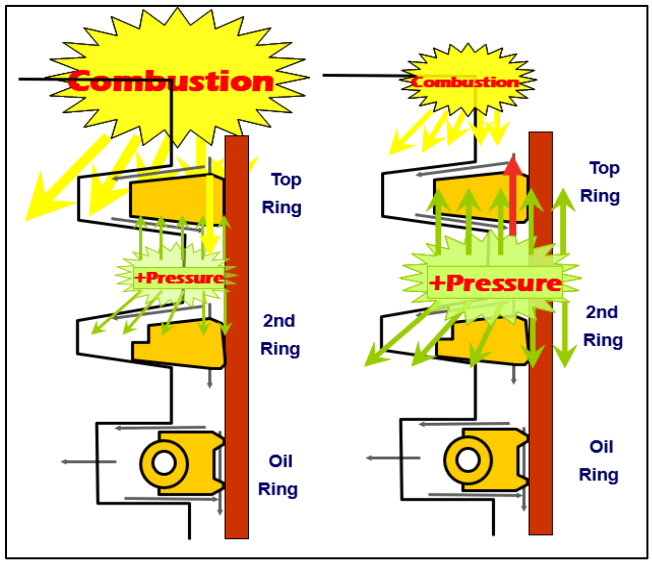

Fig. 20. Illustration of Inter-Ring Gas Pressure over Power Stroke.

It is desired to move the cross-over to the right will typically lower the reverse blowby which is better to minimize reverse blow by as minimized post changes in fig 21.

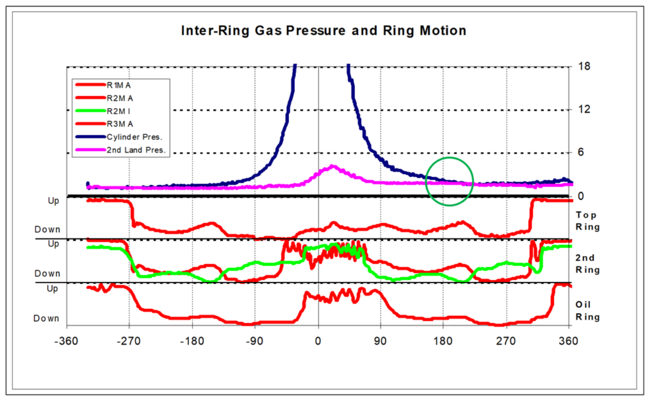

Fig. 21. Illustration of Gas Pressures Across Thermodynamic Cycle for Post Ring Dynamic Improvements.

Ring dynamic analysis with the existing ring pack was performed for operating points shown in Table 4. All the relevant inputs were fed into the simulation model to perform the analysis for the baseline piston ring pack for further optimization.

TABLE 4
Operating Points for Simulation.

Operating Point	Speed (RPM)	Torque (%)
1	800	5
2	1100	100
3	1500	100
4	2300	100

The simulation model was calibrated using the test cell data to match the blow-by, oil consumption trends for initial pilot runs. Analysis showed higher reverse blow by at low load and speed points as an indication to high oil transport into the combustion chambers as shown in Table 5. Moving the cross-over to the right will typically lower the reverse blowby which is better. The combustion and inter-ring pressures traces are shown in Fig. 22 for selected operating points. This indicates that oil transport due to gas dynamics is a dominant mechanism for low load duty cycles.

TABLE 5

Reverse Blow by Results with Existing Ring Pack.

Operating Point	Cross Over (Degrees)	Reverse blow by
RPM	Degree	(% of Forward blow by @ Rated speed)
1	XX	11%
2	YX	19%
3	154	22%
4	200	3%

The results highlighted the need of reduction in reverse blow-by to improve the oil consumption at low load points.

Calibrated ring dynamics model was further used to identify the design factors to reduce the reverse blow by and hence the oil transport into the combustion chamber. DOE was set up to optimize end gaps for top and mid ring. Results showed need of increase in 2nd ring end gap to eliminate or reduce the reverse blow-by across operating points. Increasing the 2nd ring end gap helped in reducing the inter ring gas pressures below the top land, leading to the 2nd ring flutter. However, this led to increase in forward blow by which poses challenge to breather system for maintaining desired crank case pressure at higher load and speed. Thereby top ring end gap was reduced which resulted in acceptable forward blow-by rate. Combination of 2nd ring nominal end gap increases by 33% and top ring nominal end gap reduction by 10% found to be an optimal solution.

Table 6 shows the Ring Dynamic Analysis results for the optimized top and 2nd ring pack. Cross over for torque peak points was shifted towards right and reverse blow by also found to be eliminated. Cross over point for low idle point was shifted towards right and the reverse blow by % was reduced by 50%. Reverse blow by reduction provides indicative trend for reduction oil consumption at low load. Fig. 23 further shows the improved pressure traces inside the combustion cylinder.

TABLE 6

Results with Optimized Top and 2nd Ring.

Speed	Cross Over	Reverse blow by
RPM	Degree	(% of Forward blow by @ Rated speed)
800	XX+25	5%
1100	YY+45	1%
1500	NA	0%
2300	NA	0%

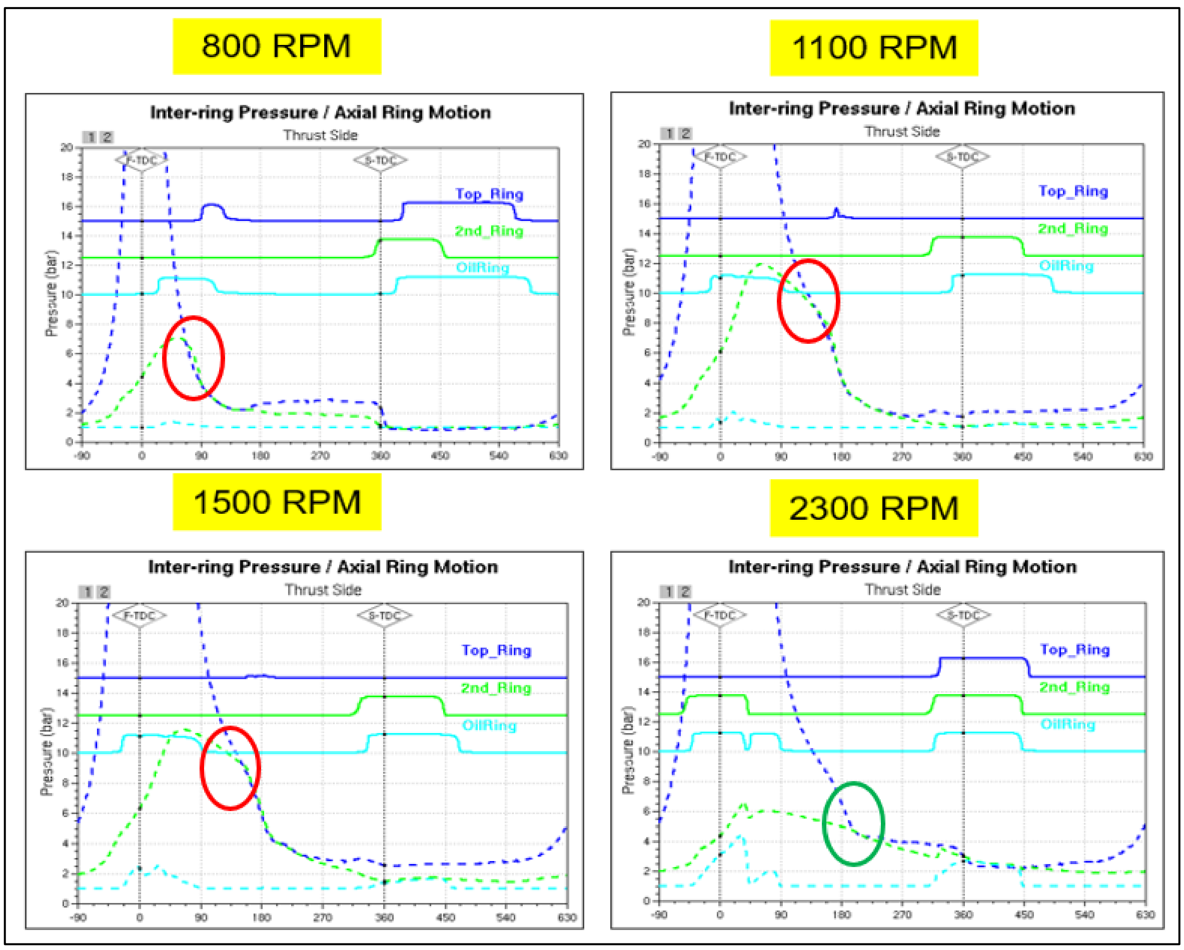

Fig. 22. Inter-Ring Gas Pressure Characteristics with Baseline Ring Pack.

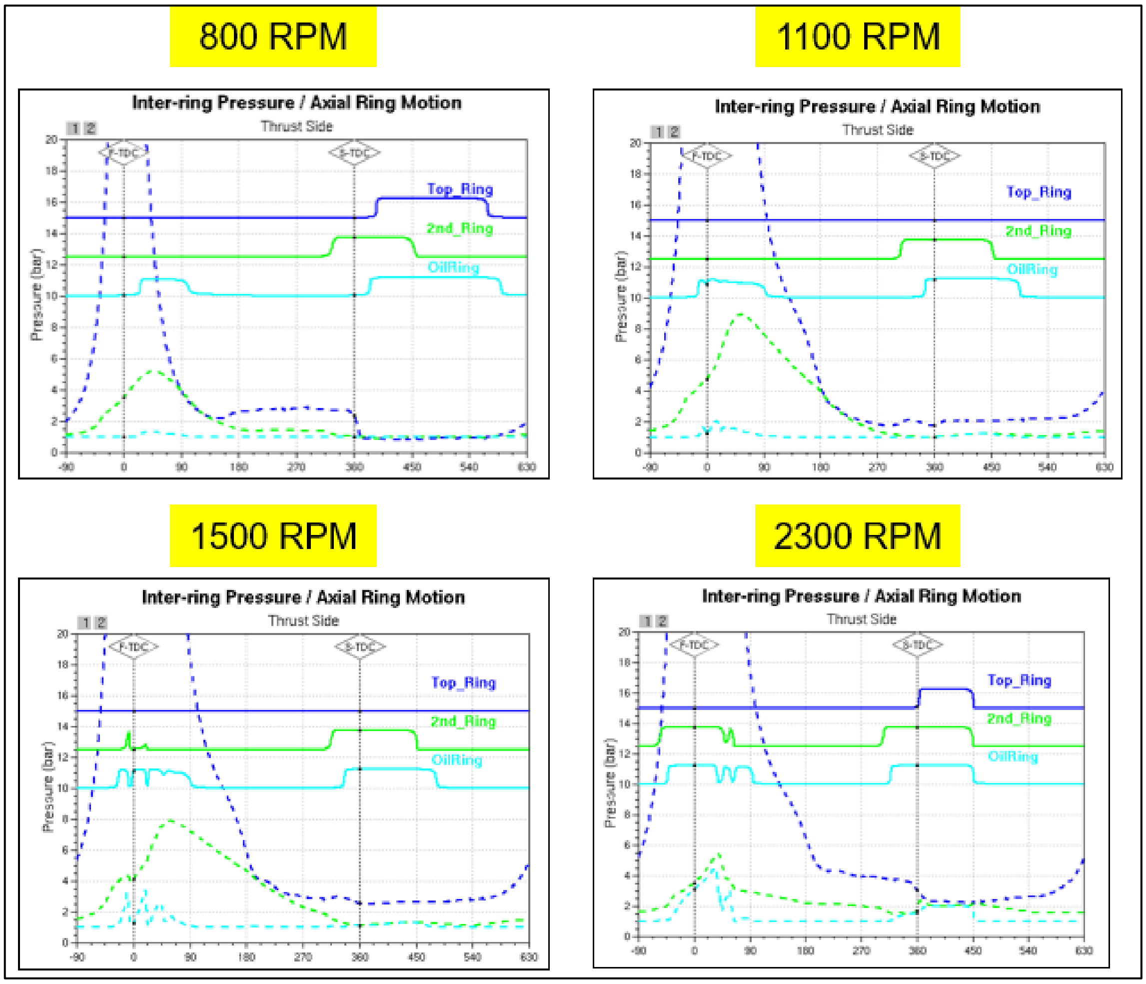

Fig. 23. Ring Motion and Inter-Ring Gas Pressure with Optimized Ring Pack.

As the above stated changes change drives oil consumption improvement at low load, a separate focus is needed for achieving improvements at high load points. The oil consumption near rated or high load points is dominated by oil evaporation and engine speed which mandates different solution strategy. Therefore, to lower the oil consumption near rated points, it was decided to lower the combustion temperature and enhance the scraping efficiency of the piston oil ring. This is expected to leave less oil on cylinder bore surface to evaporate. The former effect is achieved by making changes in the calibration and later was achieved by increasing the unit pressure of the oil ring. As the scrapping ability of the ring was improved, number of drain holes were increased for effective drainage of the scrapped oil. Nominal unit pressure increased by 13% and drain hole area increased by 50% for this study. Simulation has a limited capability to correctly predict the oil evaporation, thereby OC improvements were studied and verified through physical testing in an engine test cell.

Engine testing showed 15% improvements in OC under Transient cycle with modified oil ring as shown in Fig. 24. The similar trend was observed for steady state high load cycle. The combustion temperature reduction also shows the Oil consumption improvement by ~ 13% however it significantly deteriorated the fuel efficiency of the engine which would increase total cost of ownership for the customer. Thereby the option for combustion temperature reduction is not pursued further.

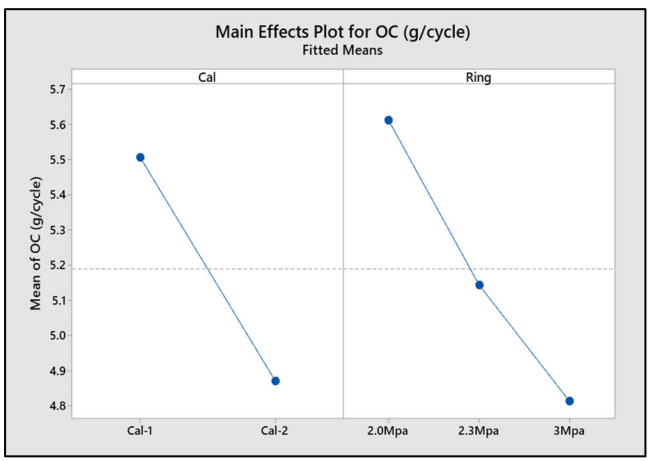

Fig. 24. Oil Ring and Combustion Temperature DOE Results.

TABLE 7

Optimized Ring Pack Solution.

Design parameter	Baseline Ring	Optimized ring
Top ring end gap (Nominal)	X	0.89 * X
2nd ring end gap (Nominal)	X	1.5 * X
Oil ring unit pressure (Nominal)	X	1.15 * X

Table 7 shows optimized piston ring pack as combined output of simulation and testing work. The oil consumption performance of engine with optimized ring pack is verified using engine test cell. The engine test cycles used are described in the following section before presenting the results.

Engine Test Cycles for Verifying Improvement

As discussed earlier, high load operating is dominated by oil evaporation whereas the low load operation is dominated by oil transport. The very first challenge for verification of ring pack solution is to have reliable inhouse test cycle to demonstrate real oil consumption improvements. The test cycle needs to simulate the vehicle duty cycle operations, transients etc such that the trend for oil consumption change can be reliably demonstrated on vehicle as well. Further repeatability and reproducibility of measurement results is a key requirement especially for low load duty cycle as absolute oil consumption values are lower, yielding higher measurement uncertainty. To address the issue, two separates in house test cycles were used for High load and low load operation respectively to conduct Design of Experiments.

Fig. 25 shows the test cycle used for high load operation and applications like Tractor. The cycle runs more than 60% at rated power and peak torque and is selected to study critical parameters contributing to oil evaporation at high load. Figure 26. shows another cycle which simulates closely the low load and transient operations of applicationslike mining tippers.

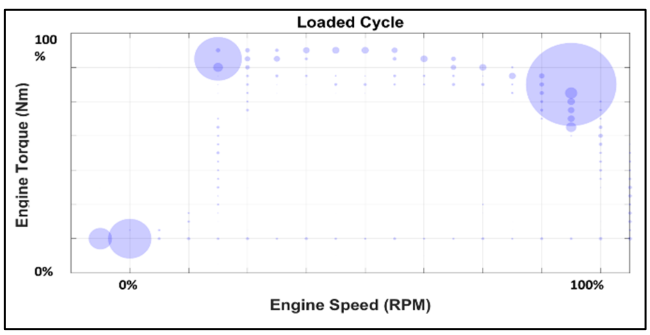

Fig. 25. Loaded Test Cycle (LTC).

Oil Consumption Results

The final ring pack solution as shown Table 7 was tested in engine test cell using Loaded and Highly Transient cycle. The results showssignificant improve-ment to the extent of ~40 % in oil consumption per cycle over baseline as shown in Fig. 27 and Fig. 28. The test cell results thus confirm the suitability of the final solution for low load as well high load applications.

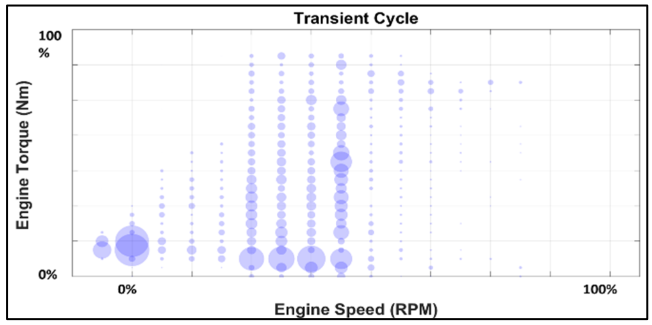

Fig. 26. Highly Transient Cycle (TC).

Blow by trend was also verified for the new ring pack to understand the limitation from breather capacity and engine emission side. Back to back blow by mapping trials were conducted using existing ring pack and optimized ring pack.

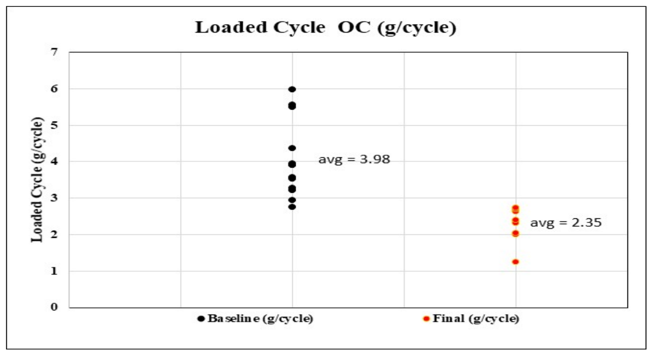

Fig. 27. Loaded Cycle Test Cell Results.

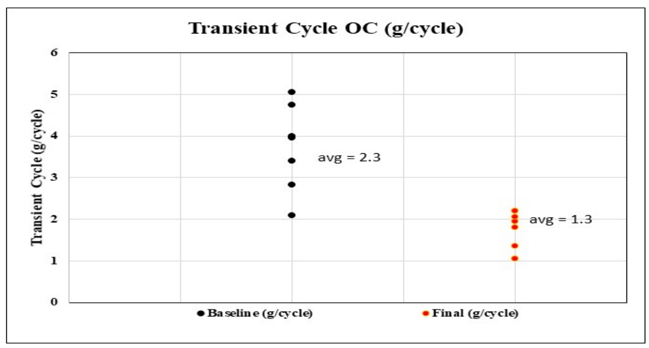

Fig. 28. Transient Cycle Test Cell Results.

As shown in Fig.29 rated speed blow by was observed to be unchanged however Increase in blow by at low speeds was observed because of 2nd ring flutter. Increase in blow by at torque peak was found to be meeting the breather capacity.

The further work is extended to validate the solution on the real vehicle applications in the field.

Oil Consumption Reduction Demonstration on Vehicle

The solution at vehicle level includes the combination of Idle shut down feature, calibration improvement and optimized piston ring pack.

The solution was implemented on 2 tipper units and the vehicles were run for approximately 800 hrs. each. Oil consumption on tipper application improved by almost ~50% in mean value over baseline as shown in Fig 30.

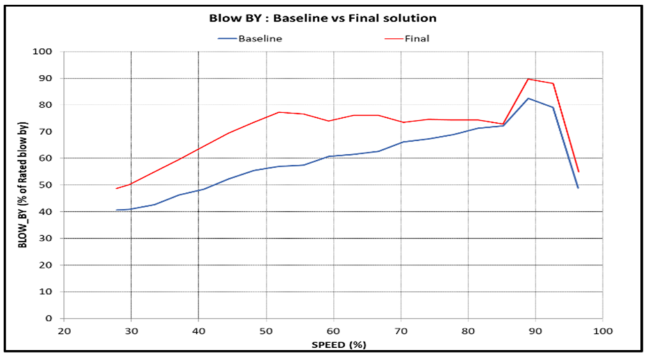

Fig.29. Blow by Trend: Baseline vs Final Solution Ring Pack.

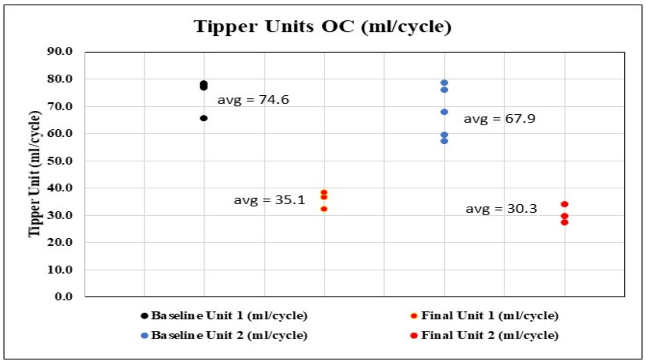

Fig. 30. Tipper Field Testing Units Results.

Regarding understanding the improvement on high loaded applications like Tractor, the solution was implemented on one tractor unit and the vehicle was run for approximately ~60K kms. Oil consumption on tractor application improved by almost ~45% in mean value over baseline as shown in Fig 31.

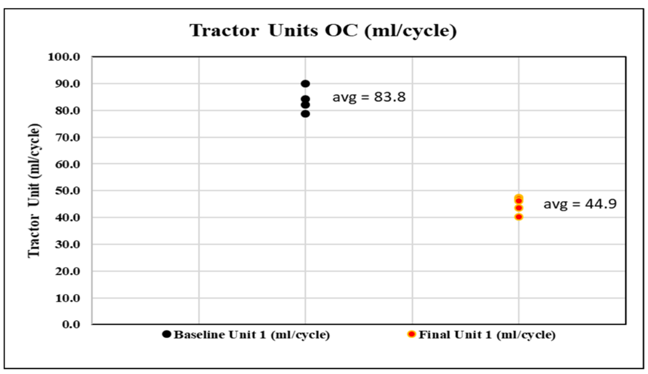

Fig. 31. Tractor Field Testing Units Results.

Durability Assessment/Validation of Final Solution on Engine Endurance Testing

The optimized ring pack solution introduces few failure modes like end gap butting, higher blow by, low oil film thickness etc. To validate the solution the optimized ring pack was tested under elevated temperature endurance cycle to check the durability and performance.

The elevated temperature test is performed at high load and elevated levels for Intake manifold air temperature and coolant temperature.

The engine tear down and critical parts inspection exercise was completed post endurance test. Fig. 32 shows the conditions of the rings for Cylinder 6, which is generally the hottest cylinder based upon cooling schematics.

Fig. 32. Tear Down Condition for Cylinder 6 Post Endurance.

Tear down observations shows no top ring scuffing or end gap butting observed. Uniform face contact and wear acceptable. No scuffing, Siamese area and ring polishing marks are observed but cross hatch is intact hence acceptable. No visual bowl rim crack – Dent/chipping observed. No under crown and cooling gallery exit coking observed. Slight carbon deposition on top and second land observed which is normal trend. No pin jamming observed, no distress or material transfer observed in any of the pin bore. No valve to piston contact observed.

The successful validation of the final ring pack is completed, and the solution was implemented in the production for BS-VI vehicles across all applications.

Conclusion

The oil consumption mechanisms are studied in detail for advance emission architecture. The oil transport found to be dominating mechanism at low load while oil evaporation found to be dominant at high load points. The simulation results enabled to optimize the Top and 2nd ring dimensions to reduce oil consumption at low load. The combustion temperature and oil ring tension are modified to reduce oil consumption at high load. The two different test cycles are devised to measure and assess the oil consumption improvement trend. The optimized ring pack provided significant oil consumption improvement of the order of ~50% over baseline or known earlier benchmarks at engine level for both low and high load operations. The vehicle trials were conducted for mining tipper and tractors. The Idling percentage and intake manifold pressure due to thermal management found to be playing critical role for oil consumption.

The final solution at vehicle level includes the combination of optimized ring pack, idle shut down feature and calibration improvement. The vehicle trials demonstrated ~50% reduction in oil consumption for Tipper application, whereas ~45% reduction for Tractor duty cycles. The piston ring pack is successfully validated using in house long hour endurance test. The solution is implemented with its merits in BS-VI automotive products for all applications.

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