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A Differentiated High Performance Diesel Engine Oil for Heavy Commercial Vehicles

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ABSTRACT

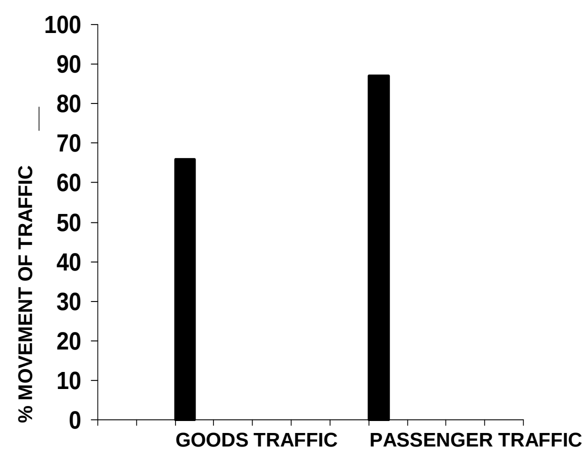
Evolution of a specific lubricant quality and design comes as a result of advances made and/or increased operational stress related to design and service condition of the hardware. Improved engines demand a lubricant that not only maintains the parts clean and free from deposits but also maintains its properties throughout the operation time. With no sign of easing of the pressure on heavy duty commercial vehicle industry, demands on the lubricants look set to grow. The need to understand the engine design technicalities, customer and commercial drivers and then to enhance product benefits is a major challenge that will only be met by differentiated formulations. This paper presents the details on optimization of a high-end heavy duty diesel engine oil [HDDEO] formulation for rationalizing the requirements of all working coordinates of designs, operations and environmental requirements for the population mix of heavy commercial vehicles in Indian sub-continent in general, and an identified OEM as a bench mark in particular. This development and optimization program utilizing Indian Base Stocks has also been worked out for effectively fitting into the matrix for global operations through OEM approval.

INTRODUCTION

Commercial vehicle [CV] industry in India, being the 4th largest manufacturers of CVs in the world is playing an important role in the Indian economy [figure 1]. This is evident from the fact that the total Indian Truck Market exceeding 5 tons had been 300,000 for FY 2006-07. Today's diesel motive power industry, therefore, presents a dynamic competitive landscape marked by consolidation of performance attributes synergistically merging with operating features, thereby resulting in the emergence of new product concepts for high speed diesel engines. Such product concepts need to be technically differentiated in respect of performance

attributes and validated stage-wise from laboratory to on-road applications.

Fig.1 % Movement of Indian Traffic



This paper establishes superior performance attributes of a test oil in the laboratory screening test matrix comprising of defined variables of optimization with respect to both the performance additive systems and base oils. Progressive validation has been made both for oil property indices and engine durability in endurance tests in engines from a major OEM having an effective presence in Indian heavy duty vehicle segment. Analyses of used oil samples indicate useful oil life being retained in excess of 40000 kms accumulated in an exhaustive field evaluation program as compared to the industry baselines of 20000 kms for similar service The predictions of high drain potentials from laboratory protocol are significantly validated in the engine tests to endurance tests and established in exhaustive field trials.

TEST LUBRICANT DESIGN & OPTIMIZATION

The candidate heavy duty diesel engine oil [HDDEO] for commercial vehicle segment, was formulated through a multi-stage optimization protocol using a detergent-inhibitor at a treat rate to impart 10 TBN to a SAE 15W-40 viscosity grade lube oil and a shear stable viscosity modifier in severely hydro-processed base stocks [table 1]. The formulation was developed within the domains of read-across criteria for lube oil inter-changeability to conform to API CH-4 and ACEA E7-04 base line specification.

Table 1 Physico-Chemical Data on HDDEO

S.NO	PARAMETER	HDDEO
1.0	VISCOMETRICS	
1.1	KV @ 100 ^{o}C, cSt	14.47
1.2	KV @ 40 ^{o}C, cSt	105.63
1.3	Viscosity Index	139
1.4	Apparent Visc @ - 20 ^{o}C, cP [CCS]	4600
1.5	Apparent Visc @ - 25 ^{o}C, cP [MRV]	26500
1.6	Apparent Visc @ 150 ^{o}C, cP [HTHS]	4.2
2.0	Pour Point ^{o}C	-27
3.0	Sulfated Ash,%wt	1.38
4.0	TBN, mgKOH/g	10.7
4.1	TAN, mgKOH/g	1.8

PERFORMANCE ENGINE TESTS

The engine tests include those conforming to ACEA E7 in conjunction with API CH-4 baseline. Additional engine test features on key performance attributes viz., oxidation stability, dispersant effectiveness and cam wear from some other identified and/or representative engines have also been included as additional inputs [table 2].

Table 2 Engine Test Profile for HDDEO

SR. NO.	ENGINE TESTS	API CH-4	ACEA E3-96	ACEA E5-99	ACEA E7-04	HDDEO
1.	CAT 1K	+				+
2.	CAT 1P	+				+
3.	MACK T8		+	+	+	+
4.	MACK T8E	+		++	++	++
5.	MACK T11	+				+
6.	CUMMINS M11	+		+	+	+
7.	MACK T9	+				+
8.	GM RFWT	+				+
9.	SEQ IIIE	+				+
10.	OM 602A		+	++	++	++
11.	OM 364LA		+			+
12	OM 441LA			+	+	+
13.	MACK T10				+	+

ENDURANCE TEST

The endurance test utilized new Euro III engine installed after measurements to carry out endurance tests, basically to assess oil performance in terms of engine life and performance. The test was conducted on a 6.87 lts representative Euro III engine of 108x125 mm bore and stroke with a rated power of 280 hp @ 2400 rpm. The 6 cylinder, in-line, water-cooled, turbocharged inter-cooled engine used cycles consisting of maximum torque, maximum power, and alternating load cycle for 375 hours. The bench test protocol utilized 375 hrs of oil change interval corresponding to 37500 kms. The oil samples collected after specified time interval were analysed for property indices.

The endurance tests were carried for a cumulative 2250 run hours corresponding to a cumulative of 200,000 engine kms.

FIELD EVALUATION

Field evaluation used two different protocol for stage-wise validation. The Ist stage validation included 4 vehicles viz., 40L28 Tractor Head [1 no.] , 49L28 Tractor Trailor [1no.], 25L28P-1 Trucks [2 nos]. Used oil properties at respective oil drains were used as bench line data base. The IInd stage validation included trend analyses of the used oil data in an HCV representative of an OEM segment of Indian Commercial Vehicle industry with full range of trucks from 16 GVW to 49t GCW. The data analyses corresponded to accumulated distance of 20000 kms, the industry bench mark for severe duty service to an extended drain period of 40000 kms, the differentiated bench mark.

RESULTS AND DISCUSSION

Differentiating Logic

Recent years have witnessed increased complexity in lubricant specifications. Hence after defining baseline performance levels, further test protocols are added to formalize differentiated product line. Our earlier papers[1-2] defined the requirements for appropriate specifications viz.,CCMC D-5 in 1990s to a Global DHD-1 in early 2000 to merge with the-then operation and/or design requirements. With global specifications as baseline, endurance test as add-on would offer tangible performance benefits by delivering performance attributes specific to subject engines[3-5]. Since not only differentiable attributes of performance but also reliability of performance has been fundamental in maintaining bench marks and ensuring design integrity, the opportunities for improvements are also identifiable. In view of all such perspectives, and additional requirements of sustaining useful oil property indices at longer drain while complimenting the Euro III engine designs with a significant safety margin the lube oil design of the HDDEO has been worked up meet ACEA E7-04. The differentiated lubricant design is, therefore, expected to perform in 25 to 50 tons heavy duty segments of both mainstream and multi-axle trucks.

Differentiating Engine Oil Attributes and Test Programs

Laboratory Test Protocol

The paper worked on the concept of base line shift to higher performance by bench marking development program on the current established standards [table 3].

Table 3 Laboratory Test Data on HDDEO

S.NO	PARAMETER	HDDEO
1.0	**VOLATILITY, %wt**	5.0
2.0	**DISPERSANCY** % Viscosity Increase at End-of-Test	5.23
3.0	**DETERGENCY** PANEL COKER Wt Gain, mg	28.5
4.0	**THERMAL STABILITY [144h]** %vis change at 100 C	0.40
5.0 5.1 5.2	**OXIDATION STABILITY** On-Set Oxidation [DSC] Induction Time [MICRO-OXIDN]	 299 118
6.0	**SHEAR STABILITY INDEX**	23
7.0 7.1 7.2	**4-BALL WEAR TEST** WSD,mm [1800rpm,40 kg,75 C,60mins] WSD,mm [1800rpm,60 kg,75 C,60mins]	 0.45 0.55
8.0	SRV FRICTION WEAR TEST WEAR SCAR DIA, mm FRICTION COEFFICIENT	 0.45 0.12

Oxidation stability of diesel engine oil not only influence the useful oil life but also affects such related performance attributes as wear, base depletion, deposits and thermal degradation. Experimentation protocol involved the evaluation of antioxidants for delaying the onset of oxidation. Further experimentation focused primarily on evaluation of secondary antioxidant acting as peroxide decomposers in reducing the alkyl hydro-peroxide to alcohols, and further on to optimization of primary-secondary antioxidants. Higher incipient oxidation temperature and longer oxidative induction time are indicative of thermo-oxidative stability [table 3].

Engine Test Data

The profile of engine tests carried out to optimize HDDEO address adequately Euro III engine designs and operational requirements in terms of key performance attributes like soot related viscosity control, valve train wear, oxidation inhibition, high temperature deposit and corrosion control and durability[table 4].

Endurance Tests

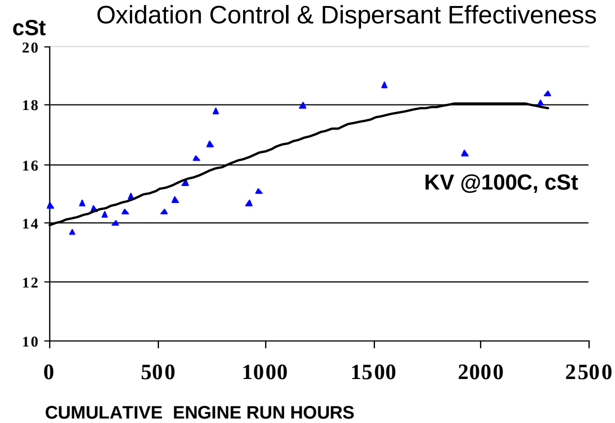
Endurance tests provide a useful tool to evaluate engine performance in a systematic manner[3-5]. The endurance test has been carried for a cumulative of 2250 run hours corresponding to 200,000 engine kms in multiples of run cycles, each corresponding to 37.5K engine oil kms. The used oil parameters are within the tolerance limits indicating usefulness of the lube oil for ~40000 kms which is double the industry drain period of 20000 kms under severe operations.

Table 4 Engine Test Profile for HDDEO and Relevance

PERFORMANCE	ENGINE TESTS	HDDEO
Soot Dispersancy [2.5%soot]	Mack T8	ACEA E7 API CH-4
Soot Dispersancy [3.8%soot] [4.8%soot]	Mack T8-E	ACEA E7 API CH-4
Soot Induced Valve Train Wear	Cummins M11	ACEA E7 API CH-4
Oxidation	Seq IIIF [IIIE]	API CH-4
Piston Deposits	Cat 1P/1R	API CH-4
Oil Consumption	OM 441LA	ACEA E7
Bore Polish	OM 441LA	ACEA E7
Bore Polish	OM 364LA	ACEA E3
Ring/ Liner / Bearing Wear	Mack T-9	API CH-4
Ring/ Liner Wear	Mack T-10	ACEA E7
Roller Follower Wear	RFWT	API CH-4
Corrosion	Mack T9,HTCBT	API CH-4
Aeration	Navistar HEUI	API CH-4
Shear Stability under severe conditions	90 Cycles	ACAE E7

Stable oil viscosity is an indicator of the candidate oil's ability to effectively disperse soot and prevent oil oxidation. Endurance test has indicated identical slope of viscosity increase for 6 run cycles corresponding to 37500 oil kms for each run cycle. The engine oil HDDEO has retained its structural integrity over 200,000 cumulative engine kms accumulated through 6 cyclic runs in the endurance test [fig.2].

Fig 2 Trace showing Stable Oil Viscosity
Oxidation Control & Dispersant Effectiveness



Dispersant effectiveness of HDDEO established in Leyland followed by Mack T8E engine tests is validated in the endurance test also. The stabilized viscosity over the cycle tests corresponding to 37500 oil kms repeated to attain 200000 cumulative engine kms [fig.2], is due to the ability of HDDEO in effectively dispersing the contaminants viz. soot. The simultaneous trace of soot content determined by TGA and hexane insolubles determined by ASTM D-893B at the end of cumulative 2250 engine endurance hours indicate insignificant insolubles for a significant soot content [fig.3]. The endurance test indicates a high dispersant index and hence long drain potential of HDDEO.

Fig 3 Traces showing Low Insolubles for Significant Soot Content:

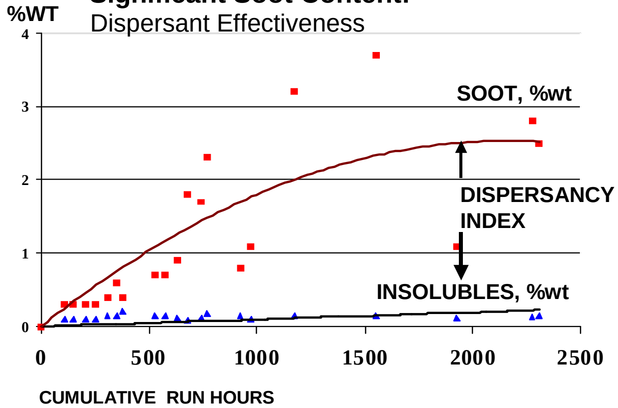


Fig 4 Traces showing Effective Base Reserve

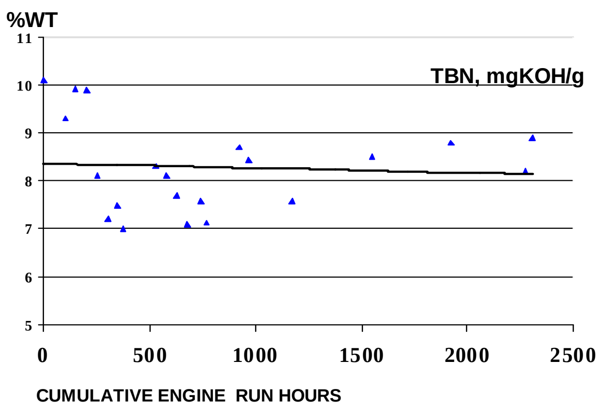
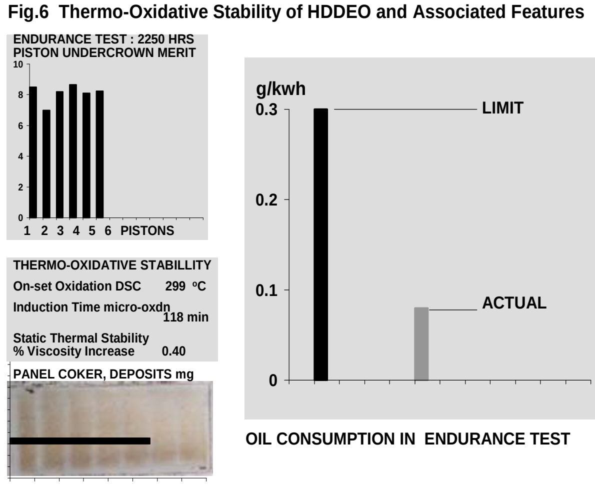


Fig.6 Thermo-Oxidative Stability of HDDEO and Associated Features



The TBN drop has been minimal [fig.4], indicative of the balanced synergy for inhibition of oxidation induction, progression and deposit formation as a result of thermo-oxidative stress. The thermo-oxidative stability rationalized from laboratory bench test to a performance engine test is, therefore, adequately validated through the results of the endurance test. The efficacy of the test oil for control of corrosive and mechanical wear is also evident from low wear metals observed in used oil.

For oil consumption of 0.3 gms/kwh, the actual test results was found to be 0.08 gms/kwh [fig.6]. Thermo-oxidative stability of HDDEO is evident from the laboratory screening test results and the piston undercrown merit rating in endurance test. Effective control of deposits resulting in oil consumption control is clearly illustrated in fig 5.

Field Evaluation

Field evaluation of the test oil HDDEO provided the final validation in respect of stabilized useful oil property indices at extended drain. The used oil attributes have been found to be in order for an oil drain period exceeding 40000 kms for severe duty service as compared to recommended drain of 20000 kms.

Ist Stage On-road Evaluation

Ist Stage on-road evaluation used 4 vehicles – Tractor Head [1 number], Tractor Trailor [1 number] and Trucks

Fig.6 Stage I Field Evaluation in Vehicle Mix at Different Drains

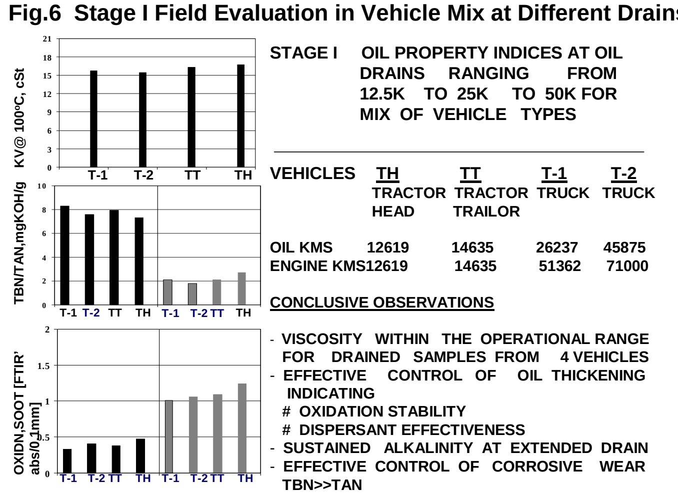


Fig 7. Stage II Field Evaluation Data showing Trend Analysis - Effective Oxidation Control and Long Drain Potential

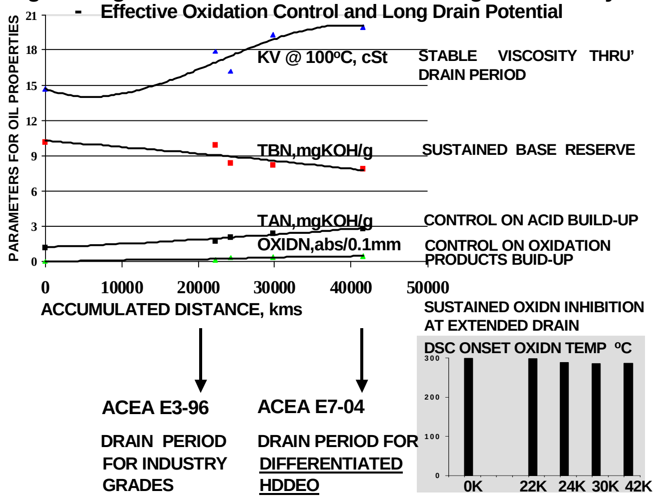
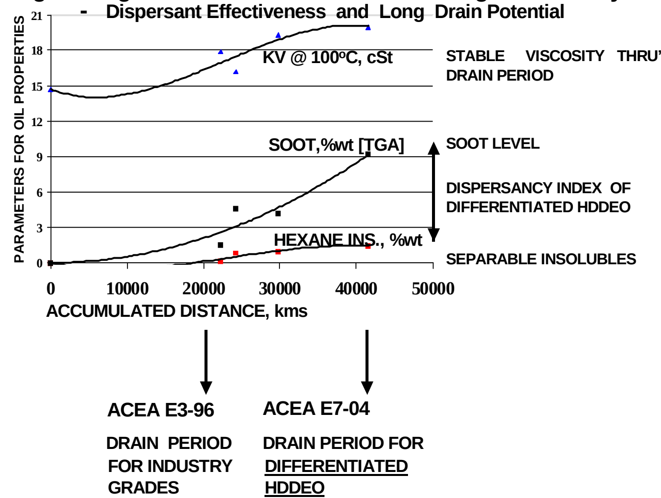


Fig 8. Stage II Field Evaluation Data showing Trend Analysis - Dispersant Effectiveness and Long Drain Potential



[2 numbers] for oil property indices at 12K, 15K, 25K and 45K oil drains respectively [fig 6].

2nd Stage On-road Evaluation

2nd Stage on-road evaluation included trend analyses of used oil samples from a vehicle accumulating a significantly high kilometrage thus suggesting satisfactory long drain potential.

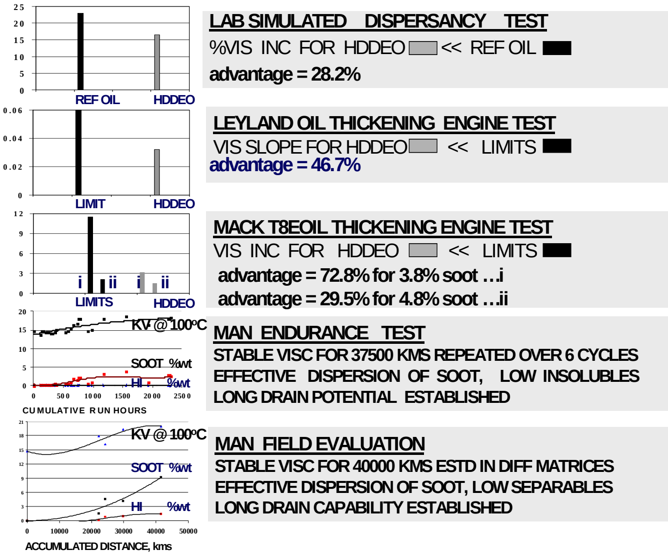
The data analyses clearly indicates effective control of oil thickening both as a function of thermo-oxidative stability resulting in inhibition of onset of oxidation and hence build-up of oxidation products and dispersant effectiveness resulting in effective dispersion of high soot content and hence control in separable insolubles. Appropriate experimental combinations have been utilized to indicate the index for oxidation stability and dispersant effectiveness [figs 7,8]. The additional requirements of PDSC of ACEA E7-04 also helped in differentiating the lube oil design of HDDEO for additional oxidation stability at extended drain.

Stable viscosity over the entire range of the operation and the trace [figs 7,8] not only indicate effective control of oil thickening but also maintaining of the structural integrity at extended drain. Revisiting our earlier work[6] of heuristic selection of an appropriate Viscosity Modifier has also resulted in meeting the additional requirements of ACEA E-7 in respect of shear stability index. This has led to differentiating HDDEO for its structural integrity at extended drain.

The domain of wear control has been addressed. While the adhesive wear control is ensured through stabilized viscosity over the entire operation range, the asymptotes showing sustained base reserve and adequate control of acid build-up [fig 7] indicate corrosive wear control at extended drain of the HDDEO.

The soot dispersion has thus been addressed from laboratory to field through stage-wise specific experimental designs for differentiating the design attributes of HDDEO. The sequence of test protocol is schematically represented in fig 9.

Fig.9 Differentiated HDDEO Lube Design for Soot Dispersion



The field evaluation has been able to establish stage-wise the long drain capabilities of differentiated HDDEO to be exceeding 40000 kms as compared to industry specific 20000 kms for severe duty operations.

CONCLUSIONS

- The specific lube oil design requires certain identified attributes to be added in and evaluated for matching the current generation heavy commercial vehicle engine appetite.

- The bench tests and performance engine tests over and above the specified tests are necessary to distinguish a formulation addressing the specific needs of a typical operation.

- A Heavy Duty Diesel Engine Oil HDDEO has been designed using appropriate additive system and viscosity modifier to meet API CH-4/Global DHD-1 / ACEA E7-04 specifications to meet the long drain requirements of heavy commercial vehicles, while sustaining lube property indices in an environment generated out of the Euro III designs requirements.

- The lube oil design in HDDEO has been differentiated by stage-wise validation of the attributes in laboratory test protocols, engine test matrices, endurance tests and field evaluation programs of the identified OEM.

- For the identified OEM, the lube oil design of HDDEO has been differentiated to reach long drain potential of 40000 kms for severe duty service in comparison to 20000 kms industry base line.

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Fig 8. Stage II Field Evaluation Data showing Trend Analysis - Effective Oxidation Control and Long Drain Potential