Turbocharger Deposits and Engine Deposits – A Duality:
II –Bench Test Studies of Engine Piston Deposits

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Abstract

The problem of engine deposits caused by oxidation, thermal degradation, and other forms of engine oil decomposition during its service in the engine has been a challenge since the development of the now-ubiquitous Otto-cycle engine a century and a half ago. The problem has led to progressive development of decomposition-resistant engine oils as engine design has made the engine increasingly dependent on the engine oil to provide adequate deposit protection and, at the same time, a harsher environment for the oil.

A critically important area of deposit formation is the ring-belt area where small amounts of lubricant are subject to the hot and chemically active blow-by gases of combustion. Prevention or slowing of deposits in this area is important in obtaining engine dependability, efficiency, and durability. Over the years, subjective methods of visual appraisal and rating of the condition of pistons after engine or field tests have been the principle means of determining engine oil resistance to such deposit formation.

This paper presents the development and application of an objective test – the TEOST MHT protocol – a gravimetric bench test of the susceptibility of engine oils to piston ring-belt deposits. It also compares the deposit response of over two thousand engine oils collected around the world in this TEOST MHT bench test.

Introduction and Background

The close relationship between the automotive internal combustion engine and the engine oil chosen for the engine's lubrication is particularly defined by the ability of the oil to control engine deposits. When they occur, such deposits can offset effective lubrication particularly in the piston ring-belt area which is highly vulnerable to deposit formation.

Deposits in the Piston Ring-Belt Area

Although the mass of piston ring-belt deposit is relatively small compared to other engine locations and forms of deposit/sludge generation, the effect of ring-belt deposits on engine operation is disproportionately large. Such deposits restrict or alter piston ring operation during the rapid reciprocating motion of the piston. Deposits can distort the desired orientation of the ring faces to the cylinder and thus reduce the ability of the rings to seal the combustion chamber in garnering the energy benefit of combustion. Moreover, this loss of effective sealing increases both combustion gas blow-by into the crankcase as well as oil loss into the combustion chamber. These losses, in turn, reduce engine efficiency and increase the presence and growth of chemistry adverse to engine oil life and effectiveness **[1]**. Greater presence of engine oil in the ring-belt area also increases the rate of deposit formation.

Increasing use of bio-fuels and lubes with their greater susceptibility to oxidation is expected to increase ring-belt deposit problems – and need to monitor engine oil deposit tendencies.

Engine and Bench Tests

Engine Tests − The importance of piston ring-belt deposits led to the generation of several engine oil dynamometer tests among which have emerged, for example, the relatively well-known, Sequence III series in North America (presently represented by IIIG **[2])** and the Peugeot TU3M High Temperature Test in Europe (TU3MH) **[3]**. Both of these engine tests are based on subjective (visual rating) evaluation of ring-belt and piston skirt deposits.

However, engine tests are expensive to run, have limited precision, and require considerable logistics in obtaining replacement parts for engine rebuilding as well as the need to assure reasonable consistency of the fuel used – which also plays a part in deposit formation **[4]**.

Such factors often lead to the development of bench tests which − upon showing an acceptable level of correlation with a particular engine test and/or a desired evaluation of a particular lubricant property − may provide a less expensive way of developing different experimental engine oil formulations. Such bench tests may accompany engine tests or, in some specifications, have made an engine test unnecessary.

Bench Tests − As mentioned, the primary qualification for an acceptable bench test is that it correlate sufficiently well with the mechanical device being simulated as to provide benefits in time, cost, – and, particularly – information. Over the years, such bench tests have been developed as engine design and performance needs have adversely affected the capacity of engine oils available to continue to function well in increasingly more demanding service.

In regard to the varnish and deposits accompanying oil oxidation in engine and turbocharger simulating bench tests, these bench tests have often been based on subjective rating of appearance. A more desirable but also more difficult choice is to develop and use bench tests that are based on objective physical measurements of mass, volume, and/or pressure.

TEOST Bench Tests − Development of objective physical measurement of deposit mass was the rationale behind the two oxidation protocols: one, an immediately preceding paper **[5]** on turbocharger deposits, and this second paper on engine deposits – both showing the distinct duality in deposit-forming tendencies of the engine oil lubricating both mechanisms.

Both tests were separately developed using the basic Thermo-oxidation Engine Oil Simulation Test (TEOST) instrument − each protocol requiring quite different test conditions and physical components to reflect the considerably different deposit-forming environments of the turbocharger and the engine. The level of correlation found in the development of both tests led to both individually being included in OEM specifications and in the International Lubricants Standardization and Approval Committee's (ILSAC) GF series of specifications **[6,7,8,9]**.

This second paper presents the development and application of the piston ring-belt deposit bench test, called TEOST MHT ('MHT' for 'moderately high temperature' [285°C] compared to the very high temperature TEOST 33C bench test [up to 480°C]). .

TEOST MHT Bench Test − A few years following the successful development and application of the TEOST 33C turbocharger deposit bench test previously mentioned **[5]**, the author's laboratories were requested to utilize the knowledge gained to develop a bench test which would simulate piston ring-belt deposits.

It was obvious at the beginning of test development that although the protocol involving

1. objectively weighing deposit mass increase by
2. repeatedly and precisely passing a volume-element of the engine oil
3. containing a suitable catalyst over a
4. temperature-controlled, resistively-heated, steel rod

was a good approach, the conditions manifested in the ring-belt area of the engine were quite different from those causing coke-like deposits in the turbocharger. Moreover, a new set of reference oils with engine test credentials were required.

Comparative Test Design for the TEOST MHT Protocol − Accordingly, although the TEOST MHT bench test utilized the basic strengths of the TEOST instrument in temperature control and oil circulation, the protocol applied a considerably different means of exposing the oil to the rod at the desired temperature.

Since the oil lubricating the ring-belt is held to a relatively thin film, it was decided that rather than adapt the TEOST 33C approach of passing the bulk oil upward through a casing enclosing the rod at a measured rate of flow, the approach conceived for the TEOST MHT was to feed the oil to the upper end of the pre-weighed steel depositor rod and to allow the oil to flow slowly down the rod in a pattern controlled by a spiral wire pathway.

Moreover, since the piston rings are also bathed in air and combustion gases, a glass mantle enclosed the heated rod between two metal end-caps and air was passed through the mantle at a controlled rate. The difference between the appearance and the test oil exposure of the steel depositor rods serving the two TEOST applications are shown in Figures 1a and 1b.

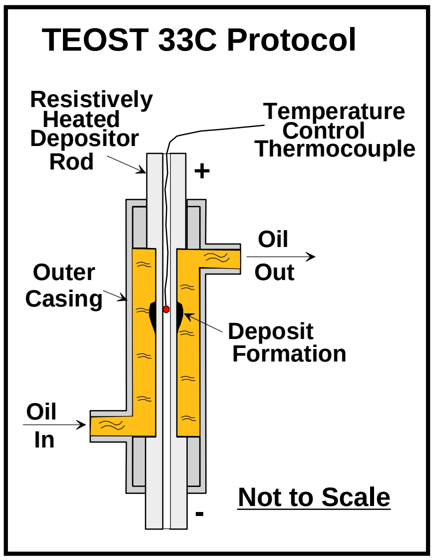
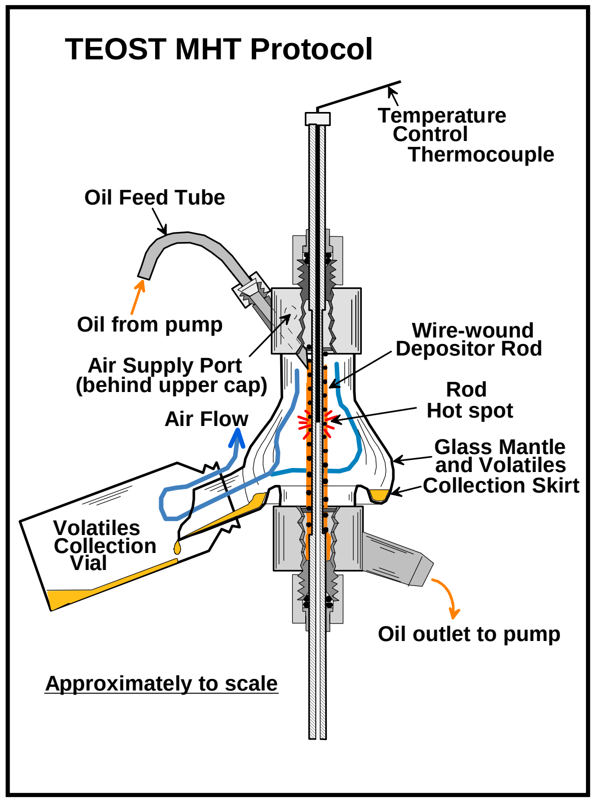


Fig 1a − Exposure of Depositor Rod to flowing oil in the TEOST 33C protocol.

Fig 1b − Exposure of wire-wound Depositor Rod to flowing oil in the TEOST MHT protocol.



Although the details of the development and application of the TEOST MHT protocol are presented in earlier papers **[10,11]**, it is believed helpful to the present reader to review some of the information carried in these papers. Recent insights are offered by Devlin, et al. **[4]**.

As in the case of the TEOST 33C turbocharger bench test, the TEOST MHT protocol measures deposit weight and utilizes measured flow of the engine oil past a pre- and post-weighed, precision-machined, steel rod. This rod is resistively heated under the control of a thermocouple inserted into the bore of the rod to the depth of maximum rod temperature set at the appropriate depth with highly oxidation-resistant reference oil flowing over the heated rod.

In contrast to the TEOST 33C bench test protocol where the rod temperature was cycled between 200° and 480°C, in the TEOST MHT protocol, to simulate engine ring-belt deposits, under severe engine operation, the rod temperature was held constant at a temperature of 285°C for 24 hours. Test sample size also varied considerably between the two TEOST-based protocols with approximately 100 mL used in the TEOST 33C protocol and 8.50 grams used in the TEOST MHT protocol.

The TEOST 33C was made ASTM Standard Test Method D6335 in 1998 **[12]** and the TEOST MHT later became ASTM Standard Test Method D7097 in 2005 **[13]**.

Basic TEOST MHT Protocol − On the basis of the ring-belt engine environment and the exposure to deposit-forming conditions in this area, the following parameters were ultimately selected:

1. Thin film oil film exposure controlled by slow oil flow, guided down a spiral wire on the Depositor Rod.
2. Exposure of the oil film to controlled rate of air flow at 10 mL/minute.
3. Relatively small test sample of 8.50 g at 0.25 g/minute.
4. Constant rod temperature of 285°C set at the thermocouple position showing the highest internal rod temperature.
5. Addition to the test oil of a precisely blended three-part tin, lead, and iron catalyst at approximately 1% of sample weight (exact weight to be added is shown on the catalyst bottle).
6. Collection and separation of volatile oil components from the sample.
7. Test duration of 24 hours.

Further and more detailed information can be found in Reference **10**

With the successful establishment of the TEOST MHT test, the instrument was incorporated in ILSAC engine oil specifications starting with GF-3 **[7]**. The TEOST MHT instrument is shown in Figures 2a and 2b.

Fig. 2a − The TEOST MHT instrument.

Fig. 2b − Close-up of depositor assembly and sample circulation path.

Correlation with the Peugeot TU3MH Engine Test − Correlation with the Peugeot TU3MH piston varnish rating deposit test was thought to be advantageous since the test had several reference oils associated with it. Moreover, since piston skirt varnish shares the same engine environment as the piston ring-belt, it was considered that it would be worthwhile to try to develop an objective bench test with some of these six oils to utilize their statistical solidity.

The TEOST MHT development work was essentially completed early in 1998 using four TU3MH reference oils. The resultant bench test protocol was then applied to the fresh oil samples of a series of 18 engine oils that had been run in 1998 and 1999 on both European and North American TU3MH test stands. Most of these TU3MH test were run as required with specially plated pistons to reduce the piston-ring groove side-wall clearance. However, several of the tests were run with only common pistons. The TEOST MHT clearly separated these TU3MH tests into two groups as reported in a 2000 paper on the TEOST MHT method **[11]**. As was shown in that paper, the correlation values given by the Coefficient of Determination for both sets of plated and common piston tests were exceptional ($R^2 \geqq 0.90$).

TEOST MHT Deposit Test Study of Engine Oils − Data and Discussion

Source of Comparative Data

Information from the Institute of Materials (IOM) Engine Oil Database (an extensive database on engine oils collected directly from the world's consumer markets for several decades) has included TEOST MHT data from 2001 to date. For this paper (as in the previous companion paper on the TEOST 33C) it was considered pertinent to compare the performance of engine oils around the world for the years 2001, 2004, and 2008 in Europe, North America and Asia using the TEOST MHT bench test.

To reduce such a mass of data to understandable and readily comparable form, distribution histograms of the TEOST MHT rod deposit data using 5 mg intervals from 5 to 95 mg were generated versus the percent of the oils analyzed falling into a given milligram deposit range for the indicated span of years.

Engine Oils in North America

As mentioned, results of TEOST MHT analyses have been part of the IOM engine oil database since 2001. Over the period from 2000 to the present, engine design has been rapidly changing with strong efforts to specify engine oils that will keep pace.

For the study of progress in reducing ring-belt deposits, it was thought to be of interest to see how engine oils collected from the three sectors of the world changed in response to this bench test protocol from 2001 to 2004 to 2008.

TEOST MHT Bench Tests on North American Engine Oils – The systematic application of the TEOST MHT bench test was initiated in North America, quickly applied by an OEM and subsequently, as noted earlier, became part of the ILSAC GF-3 specification **[6]** for both North America and Japan. Subsequently, it has remained part of the ILSAC engine oil specification for GF-4 **[8]** and recently, GF-5 **[9]**.

<u>*TEOST MHT Bench Tests for 2001 in North America*</u> – As mentioned earlier, the IOM database for 2001 was collected as a distribution histogram ranging from 0-5 mg deposits to 95-100 mg. Figure 3 shows the distribution of TEOST MHT deposit values for the 250 engine oils collected. It will be noted that 90% of the 250 oils collected had deposits lower than 47 mg and 70% of the oils less than the GF-3 maximum of 40 mg.

It is evident that there are two prominent peaks on the histogram suggesting that these may reflect different, but favored antioxidant approaches. A smaller, narrower peak is shown at 22 mg. The broader peak in the 35 to 45 mg deposit range was considered likely to reflect more than one formulary approach.

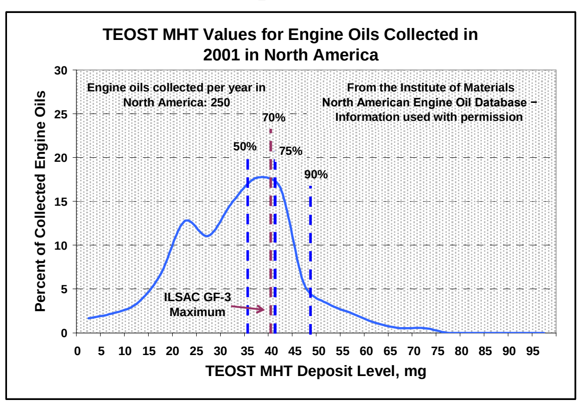


Fig. 3 − Histogram distribution of engine oils collected in North America during 2001.

Of importance: in July 2001, transition from GF-2 (for which the TEOST MHT bench test was unavailable) to GF-3 was made with a maximum of 40 mg specified. Fifty percent of the total engine oils collected by IOM during 2001 carried the 'Starburst' symbol of either the ILSAC GF-2 (88%) or the GF-3 (12%). Consequently, the shape of the histogram in Figure 3 reflects about 44% GF-2 engine oils which were not blended to meet the GF-3 specification involving TEOST MHT. More specifically, of the 15 GF-3, four exceeded 40 mg but all four were less than 51 mg. Since July 2001 was the time of transition from GF-2 to GF-3 and the first partial year of application of the TEOST MHT to ILSAC specifications, these results indicated reasonably good formulary efforts.

<u>TEOST MHT Bench Tests for 2004 in North America</u> – In June 2004, the transition from ILSAC GF-3 to GF-4 was made and the new criterion for TEOST MHT was lowered to a maximum of 35 mg. However, since IOM collects oils on the basis of market availability, no ILSAC GF-4 oils entered the collection. Figure 4 shows the histogram of IOM results on the 250 oils collected through 2004. ILSAC GF-3 composed 46% of the total engine oils collected.

In contrast to the histogram of 2001 (in which, for example, 90% of the engine oils had TEOST MHT deposit values less than 47 mg), in 2004 − despite almost half of the oil being identified as GF-3 with a maximum deposit limit of 40 mg − a deposit level 57 mg was necessary to include 90% of the oils.

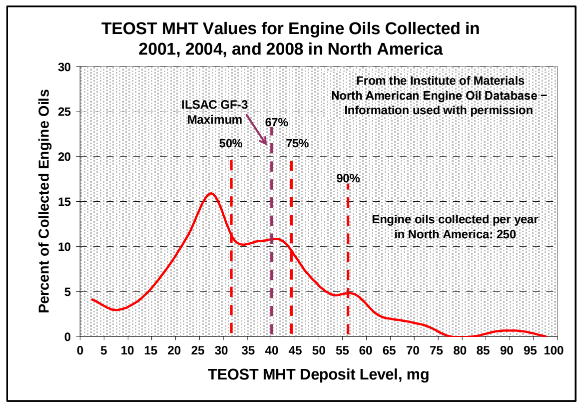


Fig. 4 − Histogram distribution of engine oils collected in North America during 2004.

As noted before, the shape of the histogram seems to reflect choices in formulation of engine oils to control oxidation by the pattern of peaks and valleys. Comparing Figures 3 and 4, the peak shown in Figure 3 at about 22 mg is no longer evident in Figure 4 although a new and strong peak with an apex at 27 has arisen. The broader peak in Figure 3 between 35 and 45 mg is still evident to a lesser degree in Figure 4. In addition, a further small and somewhat broad peak between 53 and 60 mg has newly appeared in Figure 4. Whatever the possible formulary causes of peak changes, it had a negative impact on the overall level of deposit formation for engine oils collected in North America in 2004.

<u>TEOST MHT Bench Tests for 2008 in North America</u> – In 2008, all ILSAC engine oils carrying the Starburst symbol had to meet GF-4 specifications which, regarding the TEOST MHT bench test, required deposit levels no greater than 35 mg. North American oils collected by IOM in 2008 gave the histogram shown in Figure 5. This was the first year (and related histogram) that did not contain any GF-3 formulations (since each succeeding ILSAC designation replaces the previous designation) and sufficient time had elapsed between 2004 and 2008 for GF-4 oils to replace GF-3 on market shelves.

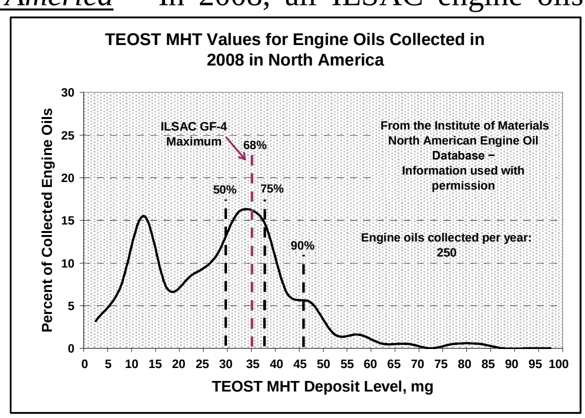


Fig. 5 − Histogram distribution of engine oils collected in North America during 2008.

As shown in Figure 5, the form of the histogram for 2008 oils changed again and reflected the influence of GF-4 specifications for the 52% of the collected oils carrying the ILSAC Starburst symbol. Interestingly, a new formulary peak has appeared below 20 mg and 30% of the collected oils fall into this low deposit range.

The previous broad peak between 35 and 45 mg has reappeared but 'moved' to lower deposit levels between 30 and 40 mg and this displacement to lower deposits may reflect the greater use of Group 2 and Group 3 base oils that themselves confer more oxidation resistance. The small peak shown between 53 and 60 mg is still evident but much smaller as the formulary practices apparently moved away from whatever approaches were previously being used producing engine oils having this level of deposit formation in the TEOST MHT bench test.

Engine Oils in Japan

IOM Collection of Engine Oils in Japan – Japanese engine oils were collected from 1992 by the Institute of Materials with later inclusion of other Asian countries. Since Japan is among the major manufacturers of passenger car automobiles, these manufacturers have also exercised a strong interest in the quality of these engine oils and their impact on warranty costs.

***TEOST MHT Bench Tests on Japanese Engine Oils* –** ILSAC specifications are also applied in Japan and it was thought of interest to see how these specifications influenced this IOM collection of 50 engine oils per year.

<u>*TEOST MHT Bench Tests for 2001, 2004, and 2008 in Japan*</u> – Figure 6 combines the histograms of 2001, 2004, and 2008 for comparison. Of all the oils collected by IOM, the percent of those identified as ILSAC GF-2, GF-3, and GF-4 oils are shown in Table 1

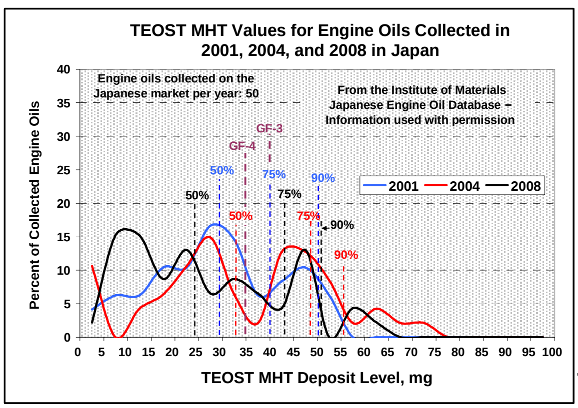


Fig. 6 − Histogram distribution of engine oils collected in Japan during each of the years 2001, 2004, and 2008.

Table 1 -- IOM Japanese Collection For Years 2001, 2004, and 2008				
Year	% ILSAC-Specified Oils			% Other Oils
	GF-2	GF-3	GF-4	
2001	24	14	--	62
2004	0	32	--	68
2008	2	0	30	68

The histograms interestingly show considerable variation from year to year although the percent of ILSAC oils in the IOM collections remains fairly consistent at about 32 to 38%. If, as previously suggested in this paper, the peaks are indicative of similar formulary approaches to the control of deposit formation; the histograms show a progression that improves markedly from 2004 to 2008 where essentially 70% of all marketed oils collected by IOM meet ILSAC GF-4 requirements for 40 mg maximum deposits in the TEOST MHT bench test.

Engine Oils in Europe

Up to the present, the TEOST MHT bench test is not required in European specifications. Accordingly, it is of interest to compare the piston ring-belt deposit tendencies of engine oils collected in this sector of the world to those in North America and Japan where the TEOST MHT bench test is required.

TEOST MHT Bench Tests on IOM Collected Engine Oils in Europe – The Institute of Materials also collects engine oils from the European marketplace. One hundred oils per year have been collected since 1992. Evaluation of these oils using the TEOST MHT bench test regarding their ring-belt deposit values began in 2001 after this test had been first accepted in the ILSAC GF-3 specification.

TEOST MHT on European Engine Oils for 2001-4-8 – Figure 7 shows the histograms obtained from the IOM Engine Oil Database for the years 2001, 2004, and 2008 as well as the 90%, 75%, and 50% levels of the oils having less than the deposit values shown. Compared to the North American histograms for the same years, the histograms are more weighted to higher deposit levels in the TEOST MHT bench test especially the oils collected in 2004.

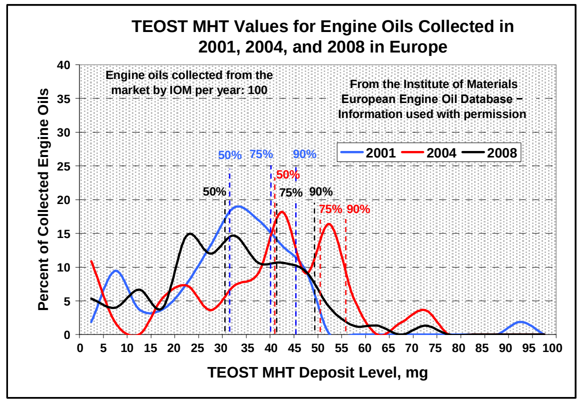


Fig. 7 − Histogram distribution of engine oils collected in Europe during 2001, 2004, and 2008.

There is also much broader distribution of the formulary approaches in controlling ring-belt deposits as shown by the number of peaks in the histograms. Even more interesting are the lack of any similarity of the three histograms of 2001, 2004, and 2008. On the basis of the TEOST MHT data, it would seem as though there are considerable formulation changes over the period from 2001 to 2008.

Overall, it is apparent from the TEOST MHT histograms for European engine that these oils are less capable of preventing or lessening ring-belt deposit tendencies than in North America. From this perspective, it will be of interest to evaluate North American engine oils in 2011 some of which will be carrying the ILSAC designation of GF-5 which will be introduced in October of 2010 and replace the GF-4 specification.

Engine Oils in Asia

With the exception of Japan, in which country JAMA, the Japan Automobile Manufacturers Association that, as noted earlier, is a member of ILSAC and its adherence to the latter's GF specifications, Asia has limited specifications for the use of the TEOST MHT bench test although the test is frequently used for appraising ring-belt deposit tendencies. Moreover, emphasis on the quality levels of engine oils has grown rapidly in accompaniment with growth of the automobile market throughout Asia.

TEOST MHT Bench Tests on IOM Database Engine Oils in Asia − The quality level of Asian engine oils varies widely in various properties of importance in engine lubrication as known by those familiar with the contents of the Institute of Materials Engine Oil Database.

This, of course, is not unexpected in any area rapidly rising in economic development and the consequential increased purchase and use of the personal automobile. Normally, with such rapid growth in the use of the automobile, lubricants made within the given country require time to meet the quality level desired. However, with the import of automobiles made in other countries, imported oils having such needed quality levels are often necessary and available. These help bridge the need for time and experience in developing engine oils within a country having the requisite qualities.

Figure 8 shows the TEOST MHT histograms for the 300 IOM engine oils collected yearly in the Asian area of the world. The data show considerable formulary variations in the peaks of the three histograms.

The year 2004 was particularly interesting in the appearance of significant peaks in the histogram above 60 mg. For that particular year, the level of TEOST MHT deposits required to encompass 90% of the data was was 72 mg, the highest level observed in this study. Even the 50% level for 2004 was found at 43 mg − higher than the 75% level of 2008 at about 42 mg.

The data from 2008 shows clear improvement in the Asian Engine Oil Database at 90%, 75%, and 50% levels as evident in Figure 8.

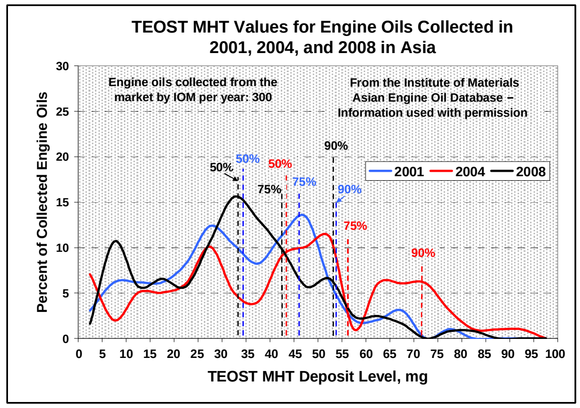


Fig. 8 − Histogram distribution of engine oils collected in Asia during 2001, 2004, and 2008.

Conclusions

Development and Application of the TEOST MHT Bench Test

The development of the TEOST MHT bench test to measure ring-belt deposits has shown very good correlation with the Peugeot TU3MH engine dynamometer test for piston skirt deposits – an area similar to the ring-belt in blow-by and thin-film deposit tendencies. The TEOST MHT bench test method was subsequently accepted by the International Lubricants Standardization and Approval Committee (ILSAC) for its GF-3 specification initiated in July of 2001. As a consequence, the Institute of Materials (IOM) added the TEOST MHT bench test to its massive, world-wide, multi-test, Engine Oil Database the same year.

Data Analysis by Generation and Comparison of Histogram — The IOM TEOST MHT data was analyzed using histograms to compare the ring-belt deposit-forming tendencies of engine oils around the world. The histograms primarily showed the percentile levels of the oils from four areas of the world, North America, Japan, Europe, and the total Asian area including Japan. Two of these areas, North America and Japan, are members of the International Lubricants Standardization and Approval Committee (ILSAC) which required the TEOST MHT bench test (ASTM D7097) in its GF-3 and GF-4 specifications and will require it in its forthcoming GF-5 specification. However, the patterns of the resulting histograms suggested that they also indicated preferred formulary approaches to deposit control.

Table 2 summarizes the deposit values that fall below the indicated percentile value shown at the head of each column. For example, 50% of the Asian oils are less than 33.7 mg. 75% are less than 46.0 mg and 90% are less than 53.5 mg.

Comparing these values in each of the three years of 2001, 2004, and 2008, provides clear discrimination of the tendency of engine oils in a given region of the world to ring-belt deposit control as well as a measure of progress or lack thereof made during this eight-year period.

Table 2 - Comparison of Deposit Levels

World Area	Year	Percentile of Oils Collected		
		50%	75%	90%
		Milligrams Deposit in Bench Tests		
Asia	**2001**	**<33.7**	**<46.0**	**<53.5**
Europe		**<32.8**	**<39.9**	**<45.7**
N. America		**<35.6**	**<41.5**	**<48.0**
Japan		**<28.8**	**<40.0**	**<48.2**
Asia	**2004**	**<43.1**	**<56.3**	**<71.8**
Europe		**<41.3**	**<50.7**	**<55.8**
N. America		**<32.2**	**<44.0**	**<56.3**
Japan		**<32.5**	**<47.7**	**<56.5**
Asia	**2008**	**<32.9**	**<42.7**	**<53.6**
Europe		**<31.1**	**<41.4**	**<48.9**
N. America		**<29.1**	**<37.4**	**<45.7**
Japan		**<23.8**	**<42.9**	**<51.0**

The Duality of Oxidation in the Engine Compared to the Turbocharger

As mentioned in the Introduction, the engine oil has increasingly broad areas to serve in the automobile. One of these areas is in lubricating the turbocharger which is becoming a much more frequent component in modern, fuel efficient, engines.

The data presented in this paper has shown the information gathered on oxidation resistance in the ring-belt area of the engine. Success in improving such resistance is found in advanced oxidation-controlling additives and base oils.

However, in the process of applying improved methods of controlling engine oxidation, it has been found and reported in a paper **[5]** coupled with this paper that some additives may weaken the resistance to oxidation found in the much higher temperature environment of the turbocharger. Thus, the challenge is to find approaches to deposit control that utilize methods of testing both environments.

Presently, the TEOST 33C has met the need to measure the response of the engine oil formulation in the turbocharger, while the TEOST MHT has been successful regarding ring-belt engine deposits. To underscore the divergence or duality of these oxidation paths, it is again of value to determine if, using these two bench test, there is any correlation between these paths. Figure 9 provides insight.

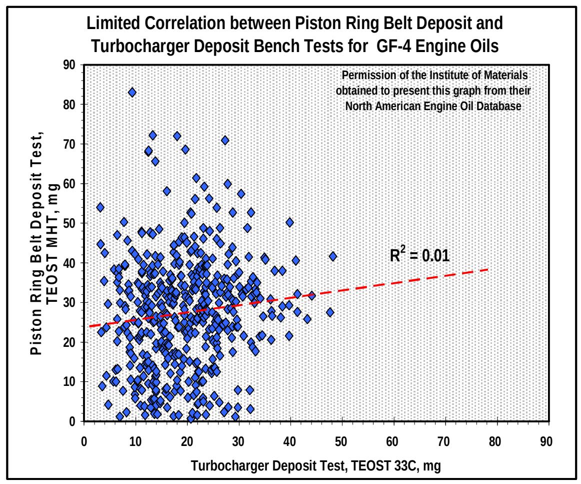


Fig. 9 − Comparison of the TEOST MHT simulating engine ring-belt deposit tendency and the TEOST 33C simulating turbocharger deposit formation tendency showing that the two areas served by the engine have very different paths of deposit formation. .

The correlation of the two mechanisms of deposit formation is shown to be very low with a Coefficient of Determination, R^2, equal to 0.01 — essentially no correlation. This information strongly indicates that to formulate engine oils to include the lubrication of the turbocharger requires careful formulation.

In a recent presentation **[14]** on the subject of testing oils using both engine tests and correlative bench tests, the author spoke to the need for recognition of evident as well as less evident assumptions in conveying the often critically important information from these tests. The above study and discussion carries the following three assumptions.

To the degree that

1. the TEOST MHT bench test simulates the ring-belt deposit tendencies of engine oils and the TEOST 33C simulates turbocharger deposit tendencies,
2. the Institute of Materials Engine Oil Database provides a reasonable range of marketed engine oils in the areas of the world represented in this study, and
3. the peaks shown in the histograms of the gathered data represent (broadly interpreted, of course) variations in engine oil formulation,

the study of ring-belt deposit control has indicated that different areas of the world have different patterns in contending with this need. This paper and the previous paper on turbocharger deposits have also shown that the deposit-forming pathways are quite different.

One question that this study did not address was that of the response of used oils to such ring-belt deposit formation. The author and his associates have considered several approaches to this question and, with hope, a further paper will be generated as part of this small series.

Acknowledgements

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