Engine Lubrication Oil Performance

By D. E. FORINGER
Gulf Research & Development Co.

All U. S. manufacturers of 1962 passenger cars recommend the use of crankcase oils of "MS" quality. In addition, one large manufacturer recommends the use of only those oils which have been tested and certified by the marketer as satisfying the engine operating sequence for Service MS. What is the significance of these statements? What does "MS" really mean with respect to motor oil performance? What are the "MS" test sequences and how are they related to the "MS" classification and to actual engine performance? There appears to be much misunderstanding about crankcase oil classifications and their performance in engines. These are the areas which this paper will explore in trying to shed some light upon this somewhat confused picture.

For the complete story on motor oil classification, it is necessary to go back to a period prior to World War II. At that time engine designs and operating conditions were such that there were no particularly stringent demands upon the crankcase oil. The major difference was that the premium oil contained an oxidation inhibitor.

During World War II considerable development work was done with engines and lubricants for military demands made it necessary to extract more output from automotive powerplants and greater reliability was an absolute requirement. At the top of these demands was the need for a greater number of engines. All these demands led to engine designs which placed greater stress on the lubricants. Tolerances were closer; parts were stressed more. The range of engine operating conditions varied drastically, for an engine might idle for days at a time and suddenly be called upon to deliver full output when an emergency arose.

However, petroleum technology kept pace with the new engine demands. Detergent-dispersant additives, antifoam agents, and better oxidation inhibitors were developed to provide better-than-ever lubricants.

After the war, engine manufacturers wanted a method of identifying these oils with improved performance, so the American Petroleum Institute was asked to set up some method of classification. Accordingly, in 1947 the API issued definitions of oil types known as "Regular," "Premium," and "Heavy Duty." The primary difference between the "Regular" and Premium" was that the "Premium" was inhibited to provide better oxidation stability, while the "Heavy Duty" had the additional advantages of possessing detergent-dispersant properties. The term "Heavy Duty" gave rise to the common usage of "H.D." frequently applied to quality oils. "H.D." has been taken, by various people, to mean either "heavy duty" or "high detergency."

In 1949 the modern V-8 engine was introduced to the American motorist by Oldsmobile with its Rocket engine. These new engines characterized by stroke-bore ratios of less than one, high compression--ratios, push-rod operated overhead valves, hydraulic valve lifters, and rigid crankcase construction--provided significant improvements in performance, quietness, and smoothness of operation. These qualities were widely welcomed by the customers, who, as they became accustomed to them, demanded even greater performance. The engines rapidly evolved in size and performance to the outstanding powerplants which we have today. However, in the process of these developments there were some growing pains: the higher compression ratios, gas pressures, and engine speeds sometimes stressed both the metals from which the engines were made and the lubricants beyond their capacity. One of the best examples of this problem is the valve train failures experienced in the early 1950's. But cooperative efforts between the oil and auto industry developed metals and lubricants which were satisfactory for these engines. However, these new lubricants possessed properties not covered in the API "Heavy Duty" classification, and it soon became evident that the oil-type designations were insufficient for specifying oils for satisfying the many service and design demands of the new engines. Accordingly, the engine manufacturers and oil industry working through the API and the American Society for Testing Materials set out to establish a more satisfactory method of motor oil classification. This joint effort resulted in a new system of Engine Service Classifications for Internal Combustion Engines with letter designations for the various services.

In devising this new classification system engine design and construction, fuel, operating conditions, and maintenance practices were considered as factors influencing lubricating oil performance. Obviously, it was impossible to include and classify all small variations in these; and the service classifications were designed so that this inclusion would be unnecessary. For example, it was recognized that an engine might operate under a variety of conditions. Under the Service Classification the oil recommendation would be made for the most severe operating conditions encountered; thus, the oil would also be suitable to handle the day-to-day variations, for these requirements would be less severe than would be that requirement for which the oil was designed.

With this brief history of the development of the API Service Classifications, the six classifications will be discussed.

GASOLINE ENGINES

SERVICE MS

TABLE I

SERVICE MS :	Service typical of gasoline or other spark ignition engines used under unfavorable or severe types of operating conditions; and special lubrication requirements for deposit, wear, or bearing corrosion control, because of operating conditions or of engine design or fuel characteristics.
SERVICE MM:	Service typical of gasoline and other spark ignition engines used under moderate to severe operating conditions, but presenting problems of deposit or bearing corrosion control when crankcase oil temperatures are high.
SERVICE ML:	Service typical of gasoline and other spark ignition engines used under light and favorable operating conditions; the engines having no special lubrication

requirements and having no design characteristics sensitive to deposit formation.

Service MS represents the most severe service encountered in the operation of gasoline and other spark-ignition engines. It includes two different types of adverse operating conditions: (1) short-trip, start-stop operations and (2) high-speed highway operation.

In the case of the passenger cars the most common type of service--short trips in which proper engine operating temperatures are not reached--is a very severe operating condition. The low engine temperatures result in relatively poor fuel combustion, and excessive quantities of soot and other residues of partially burned fuel are formed. Too, water vapors formed during combustion are condensed on the cold cylinder wall, and this water mixes with other products of combustion to form acids which promote corrosion of cylinder walls, pistons, and piston rings. Together, the water and the soot form emulsions commonly called a "sludge" which is collected in the oil rings and oil screens as well as settling out in the crankcase. In extreme cases it can cause loss of oil consumption control by completely plugging the oil rings or cause engine failure by stopping sufficient oil flow through the oil screen.

In passenger cars the severity of the problems is aggravated in the winter when lower engine operating temperatures and longer warm-up times are encountered. However, it frequently is a year-around problem in taxicabs, delivery trucks, and other vehicles used intermittently or subject to prolonged idling. The design of the cooling system, the effectiveness of crankcase ventilation, and fuel quality influence the severity of these problems.

The other type of severe operation (high-speed highway driving) results in high lubricant temperatures which promote oil oxidation and the formation of varnish. This result, of course, can lead to sticking of hydraulic valve lifters, rings, etc.

A few years ago the formulation of a single oil which would be satisfactory for both of these conditions would have been impossible. Some detergents were effective at high temperatures but not at low temperatures, while others were good at low temperatures but broke down at high temperatures. However, advances in petroleum technology have led to the development of detergent-dispersant systems which are effective under both conditions.

With either type of operation, wear might occur on highly stressed parts such as valve lifters, cans, push rods, and rocker arms unless the lubricant is properly fortified with an antiwear agent to protect against this type of failure.

SERVICE MM

This is a more moderate service requirement than is Service MS. Included in this service are vehicles powered by engines which, because of design and materials used, are relatively insensitive to deposit formation or wear when operated at high speeds or under heavy leads. But the service does not include extensive operation under severe low engine temperature service, e.g., stop-and-go driving or prolonged idling.

SERVICE ML

This is the least severe condition, and it includes moderate speed driving or moderate load operation most of the time with no severe high or low temperature operation. Engine design and materials must be such that the engine does not have any particular problems with wear. These conditions are not generally found with modern engines and driving conditions.

Since oils designated for Service ML are the lowest quality and consequently the lowest priced motor oils available, they are most often recommended for old cars with high oil consumption. However, it should be realized that even some of the older cars which are using excessive oil can encounter more difficulty by using this quality of oil if the engine has features such as hydraulic valve lifters which demand better quality lubricants.

DIESEL ENGINES

There are three service classifications for the compression-ignition or diesel engines.

TABLE II

SERVICE DS : Service typical of diesel engines operating under very severe conditions, or having design characteristics, or using fuel tending to produce excessive wear or deposits.

SERVICE DM: Service typical of diesel engines operating under severe conditions or using fuel of a type normally tending to promote deposits and wear; but design characteristics or operating conditions which may make the engine either less sensitive to fuel effects or more sensitive to residues from lubricating oil.

SERVICE DG : Service typical of diesel engines in any operation in which there are no severe requirements for wear or deposit control because of fuel, lubricating oil, or engine design characteristics.

SERVICE DS

The service requirements in this classification are the most severe encountered in the operation of diesel engines. High load operation and design factors such as supercharging cause high engine temperatures and constitute severe service; so does intermittent operation at low temperatures for this promotes wear and deposit formation. When fuels containing sulfur are burned, the sulfurous products of combustion react with the water formed during combustion to form acids; and this reaction increases service severity with respect to wear and deposits. The use of high sulfur fuels is considered to constitute severe service.

SERVICE DM

Because of factors of operating conditions, fuel character, and design features this classification is less severe than is Service DS. In the past some engines manufacturers preferred the use of DM oils rather than DS oils, even in severe service. They reasoned that the lower detergency level of the DM oils would result in less ash residue in the combustion chamber than if DS oils were used. However, all manufacturers recommend DS oils for severe diesel service.

SERVICE DG

Continuous output at near rated load or intermittent

operation under normal atmospheric conditions is considered as a normal service requirements for Service DG as long as there are no severe engine designs and there is no high sulfur fuel used.

MULTIPLE SERVICE CLASSIFICATIONS

There are two very important items which should be realized about the API Service Designation Classification.

First, any one oil might be suitable for several types of service. For example, an oil suitable for Service MS would certainly be satisfactory for the less demanding Service MM and ML. Therefore, the designation could be for Service MS, MM, ML. In addition, it might also be satisfactory for diesel engines in Service DG, in which case a DG would also be added to the other three. Most oil companies make use of these miltiple designations in labeling motor oils.

This multiple service classification of an oil has led to considerable confusion among some of the service station dealers and customers. Some engine manufacturers, for example, suggest that an ML oil not be used in their engines. However, some dealers and customers have construed this suggestion to mean that an oil in a can labeled as MS, MM, ML should not be used. This idea, of course, is not correct. As long as the maximum Service Classification shown on the can meets or exceeds the engine requirement, then the oil is satisfactory

The second item is that the presence of the words "For Service MS" on an oil can does not guarantee that the oil is a top quality oil. There are no performance tests which an oil must pass before it is labeled for some particular service. It is entirely up to the oil marketer as to what designation he is going to put on it. Of course, all reliable oil companies subject their oils to enough test to assure that they will give at least minimum satisfactory performance in the types of service for which they are recommended. However, there is a difference in the quality of oils recommedned by the various major manufacturers for the various service classifications. Some companies have elected to sell oils which just provide the minimum performance, while others with reputations for quality products build in extra performance.

ENGINE OPERATING SEQUENCES

That oils labeled "For Service MS" can and do differ in performance has caused some consternation among the car manufacturers who have reportedly experienced engine failures because of rusting, valve train wear, and excessive deposits when some oils recommended for Service MS were used. This experience led to a joint effort by the car manufacturers to further define oils which they considered satisfactory for their engines. As a result, Section G-IV of Technical Committee B of ASTM Committee D-2 has suggested a series of engine tests labeled as "engine operating sequences." Such operating sequences describe the test conditions required to emphasize the oil properties needed for satisfactory performance of passenger cars in severe service designated as Service MS. Engines made by each of the Big Three (General Motors, Ford, and Chrysler) are used in these test sequences. There are a total of 5 test sequences; the first 3 being run in an Oldsmobile engine, the fourth in a Chrysler engine, and the fifth in a Lincoln engine.

SEQUENCES I, II, III

Sequences I, II, and III are conducted consecutively in a 1960 Oldsmobile V-8 engine. Pertinent engine operating conditions for these sequences are given in Table III. Sequence I is a cam and lifter scuffing test and is run as the first part of the test because new engine parts are much more liable to give scuffing than do used parts. If after 30 cycles of operation there are no signs of engine malfunction, the test is continued to Sequence II without oil drain.

TABLE III

ASTM G-IV TEST SEQUENCES

	Sequence I	Sequence II	Sequence III
Evaluates	Scuffing and wear.	Low temperature and deposits	High temperature oxidation and deposits
Engine	-----1960	Oldsmobile	V-8-----
Speed, rpm	2500	1500	3400
Load, bhp	2	25	85
Coolant Temp, °F	95	95	200
Oil Temp., °F	120	120	265
Intake Air Temp, °F	80	80	80
Intake Air Humidity, grain/lb air	80	80	80
Air-Fuel Ratio	14.0	14.0	15 0
Operation	30 cycles of 10 min running followed by 50 min shutdown.	10 cycles of 3 hr running and 3 hr shutdown	40 hr continuous.
Fuel	-------Special Test Fuel-------		

Sequence II is primarily a low temperature engine rusting and corrosion test and consists of 10 cycles comprised of 3 hr of operation followed by 3 hr of shutdown. At the end of the 10 cycles the test is continued to Sequence III without oil drain.

Sequence III is primarily a high temperature oil oxidation test run in the presence of the oil contaminants formed during the low temperature operation of Sequences I and II.

Upon the completion of Sequence III the engine is disassembled and inspected for scuffing, wear, rusting, corrosion, sludge, and varnish.

The ASTM has set no specific levels of acceptable performance in these tests. They merely describe test procedures and leave the interpretation of the test results to those conducting the tests.

However, the car manufacturers have limits which they consider an oil should meet before it is considered by them as satisfactory for Service MS. General Motors Corporation defines these limits by reference to the engine performance of two standard reference oils in Sequence I, II, and III. One oil is used as a standard for corrosion and wear while the other is the standard for deposit formation. For an oil to be considered satisfactory, it must exhibit as good performance in the properties measured by Sequences I, II, and III as do the standard reference oils.

In addition to measuring wear and deposits, Sequences I, II, and III may be also be used to evaluate the tendency of a lubricant to promote a type of abnormal combustion known as "rumble" During Sequence III, engine rumble requirements are made by using blends of leaded isooctane and benzene as reference fuels. This procedure

is much the same as is that determining the octane requirement of an engine. The engine rumble requirement is the lowest LIB numbered fuel which suppresses engine rumble.

SEQUENCE IV

Sequence IV is conducted in a 1961 Chrysler V-8 engine and is designed to evaluate the ability of a lubricant to prevent scuffing and wear of valve tappets under high speed and high temperature operation. For this test the valve springs are adjusted to 33 per cent overload to increase test severity. Total test time is 12 hr. It is a cyclic type of operation -- two hours of operation followed by 2 hr of shutdown (Table IV). On completion of 6 cycles, the camshaft and valve tappets are removed for inspection. The condition of the parts is based on visual inspection of the engine parts.

TABLE IV

ASTM G-IV TEST SEQUENCE IV

Evaluates	High temp, high speed tappet scuffing and wear.
Engine	1961 Chrysler V-8
Speed, rpm	3600
Load	None
Coolant Temp, °F	180°F.
Oil Temp, °F	220
Operation	6 cycles of 2 hr running followed by 2 hr shutdown.

SEQUENCE V

Sequence V consists of 48 cycles of 4 hr each -- a total test duration of 192 hr (Table V)-- and is conducted in a 1957 Lincoln. The tests were designed to measure the tendency of an oil to permit the depositing of varnish on pistons and hydraulic valve lifters, the clogging of oil rings, the plugging of oil screens, and overall engine sludging. On completion of the sequence the engine is disassembled and inspected for engine deposits, wear, and rusting.

TABLE V

ASTM G-IV TEST SEQUENCE V

Evaluates	Low and medium temp deposits		
Engine	1957 Lincoln		
	1st Stage	2nd Stage	3rd Stage
Time, minutes	45	120	75
Speed, rpm	500	2500	2500
Load, bhp	0	105	105
Coolant Temp, °F	115	125	170
Oil temp, °F	125 max	175	205
Air-Fuel Ratio	9.5	15.5	15.5
Operation	Run total of 48 of above cycles.		
Fuel	Special test fuel.		

The 1962 Ford owner's manual stated that "Only those oils which will satisfy Ford Specification M-2C27 for 'Service MS' will provide proper protection and life in your engine." This specification describes, among other things, minimum rating levels for Sequence V.

As previously indicated, the ASTM has set no minimum performance levels which an oil must exhibit in the Test Sequences before it is to be labeled "For Service MS." However, it has been seen from the above that the car manufacturers have criteria for oil performance which they consider an oil should exhibit if it is to be used for severe service. Of course, from an oil marketer's standpoint, it is quite desirable to market an oil which is considered satisfactory by the engine builders. Reliable marketers do sufficient testing of their products to assure that the oils offered for a given API Service Classification adequately meet the demands of that type of service. The best assurance of obtaining an oil of the proper quality is the reputation of the oil marketer.

MOTOR OIL PERFORMANCE STANDARDS

Another system for classifying motor oils is based on actual motor oil performance standards as indicated in several types of test engines. This system involves such classifications as MIL-L-2104A, Supplement 1, Series 2, and Series 3. The MIL-L-2104A is the lowest performance level in this system of classification with Supplement 1, Series 2, and Series 3 following in that order. All these classifications define heavy duty motor oils which would be satisfactory for API Service Classifications ranging from MS to DS. The Series 2 is now obsolete and oils are no longer qualified against this specification.

Table VI lists the tests which are used for evaluating oils under these classifications.

TABLE VI

QUALIFICATION TESTS

MIL-L-2104A	L-38, L-1 (0.35%S)
Supplement 1	L-38, L-1 (1.00%S)
Series 2	1-D
Series 3	1-D, 1-G
MIL-L-2104B (Proposed)	L-38, LTD, 1-H, Sequence II

MIL-L-2104A SPECIFICATION

To qualify for MIL-L-2104A approval, oils must pass the L-38 and L-1 engine tests in addition to other physical and chemical tests. The L-38 test is conducted in the single cylinder CLR oil test engine and consists of 40 hr of operation at relatively high engine speed, moderate load, and high jacket and oil temperatures. It is designed to evaluate the oxidation and bearing corrosion characteristics of engine oils developed for use under heavy duty operation.

The L-1 is conducted in a single-cylinder, naturally-asperated Caterpillar test engine. This test evaluates oils with respect to ring sticking, deposit formation, and wear when a low sulfur content fuel is used. For MIL-L-2104A qualification a fuel containing .35 per cent sulfur is used in the L-1 test. Pertinent operating conditions for the L-1 test are given in Table VII.

Oils meeting the MIL-L-2104A are acceptable as heavy duty oils for use in both gasoline and diesel engines but under moderate temperatures and service conditions. There is no low temperature performance test in this qualification so oils of this type are not necessarily suitable for low temperature operation.

SUPPLEMENT 1 SPECIFICATION

The next higher quality oil in this method of classification is Supplement 1 which is a classification widely accepted in industry but which does not refer to any specific military or engine builder specification. Oils offered as having Supplement 1 quality are those which have met the requirements of MIL-L-2104A in the L-38 test plus the L-1 test more severe with respect to deposits and wear.

Supplement 1 oils usually have a higher additive content than do MIL-L-2104A oils. They will provide satisfactory service under more severe conditions such as diesel and gasoline engine service which includes some stop-start operation.

SERIES 2 SPECIFICATION

As previously mentioned, the Series 2 classification is now obsolete. Series 2 described lubricants meeting a specification set up by the Caterpillar Tractor Company to define lubricants which were suitable for use in heavy duty diesel engines operated on high sulfur fuels under adverse conditions. The 1-D test procedure was used to evaluate the performance of these oils. This test was conducted in a supercharged single-cylinder Caterpillar test engine and a fuel with 1 per cent sulfur was used. When compared to the MIL-L-2104A and Supplement 1 oils, the oils meeting the criteria for Series 2 provided improvements in reduction of wear and deposits with high sulfur fuels.

SERIES 3 SPECIFICATION

As newer and higher output engines were developed, it became apparent that better lubricants were needed. In 1956 the Superior Lubricants (Series 2) Specification was superseded by the Superior Lubricants (Series 3) Specification. To meet this specification it was necessary to pass both the Caterpillar 1-D test used for Series 2 qualification and a new, more severe test known as the Caterpillar 1-G test. A .35 per cent sulfur fuel is used with the 1-G procedure.

Oils meeting Military Specification MIL-L-45199 (Ord.) are essentially of the same quality as Series 3 lubricants. The military specification requires passing an oil oxidation and bearing corrosion test in addition to the 1-D and 1-G tests.

Series 3 lubricants are used primarily for high output supercharged diesel engines operating under severe conditions.

MIL-L-2104B SPECIFICATION

When MIL-L-2104A was first issued in 1950, it was recognized that lubricants meeting that specification might not give adequate protection against low temperature deposit formation. However, at that time, the additives available to give the needed high temperature performance were also not capable of good low temperature performance. Additives which are effective at both temperature extremes are now available. This fact, coupled with the need for lubricants which would give improved performance to meet the ever more stringent requirements of the military, has led to a proposed new military specification, MIL-L-2104B. Proposed Specification MIL-L-2104B describes physical, chemical, and performance requirements as well as methods of evaluating these characteristics.

Four engine performance tests are required for qualification under proposed MIL-L-2104B. These include the L-38 test for oxidation and bearing corrosion. Low temperature deposition is to be evaluated in a single-cylinder engine test which is a modification of the CRC L-43 technique; the CLR engine is used for this test. Sequence II (this test was previously described) of the ASTM G-IV test sequences is used to evaluate the protection offered by the lubricant against rusting. A high speed, high load diesel engine test known as the Caterpillar 1-H test is used to evaluate high temperature detergency and wear. The 1-H test is a modification of the 1-G test that is used for evaluation of Series 3 oils. The 1-H test is less severe than is the 1-G test and thus results in a lower deposit level.

The relative severity of the L-1, 1-D, L-G, and 1-H Caterpillar single-cylinder engine tests is indicated in Table VII which lists pertinent operating conditions.

It is anticipated that only the best of the oils meeting the Supplement 1 requirements will conform to the proposed MIL-L-2104B specification.

TABLE VII

CATERPILLAR SINGLE-CYLINDER ENGINE TESTS

	Test Procedure			
	L-1	1-D	1-G	1-H
Engine Speed, rpm	1000	1200	1800	1800
Fuel Rate, BTU/min	2950	5600	5800	4950
Intake Air Pressure, in. Hg. Absolute	Atmos.	45	53	40
Intake Air Temp, °F	Ambient	200	255	170
Oil Temp, °F	145	175	205	180
Coolant Temp, °F	175	200	190	160
Oil Change Period, hr	120	120	120	120
Test Duration, hr	480	480	480	480
Sulfur in Fuel, %	0.35	1.00	0.35	0.35