

Extending SAE J300 to Viscosity Grades below SAE 20

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Michael J. Covitch
Lubrizol Corp.

Mike Brown
SK Lubricants

Chris May
Imperial Oil Ltd

Theodore Selby
Savant Inc

Isabella Goldmints
Infineum USA LP

David George
Chevron

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ABSTRACT

The SAE Engine Oil Viscosity Classification (EOVC) Task Force has been gathering data in consideration of extending SAE J300 to include engine oils with high temperature, high shear rate (HTHS) viscosity below the current minimum of 2.6 mPa·s for the SAE 20 grade. The driving force for doing so is fuel economy, although it is widely recognized that hardware durability can suffer if HTHS viscosity is too low. Several Japanese OEMs have expressed interest in revising SAE J300 to allow official designation of an engine oil viscosity category with HTHS viscosity below 2.6 mPa·s to enable the development of ultra low friction engines in the future. This paper summarizes the work of the SAE EOVC Low Viscosity Grade Working Group comprising members from OEMs, oil companies, additive companies and instrument manufacturers to explore adoption of one or more new viscosity grades. Past studies relating HTHS viscosity to engine wear will be reviewed, and an analysis of the rheological properties of commercial SAE xW-20 oils will be presented. New data will also be offered to demonstrate the feasibility of formulating engine lubricants to meet HTHS

viscosities as low as 1.7 mPa·s while meeting current low temperature oil starting viscosity and ILSAC volatility requirements. Finally, the paper will address the measurement precision of current HTHS methods on prototype low HTHS engine oils.

INTRODUCTION

The Engine Oil Viscosity Classification (EOVC) Task Force is a standing committee of SAE Technical Committee 1 formed in 1975 [1] for the purpose of overseeing SAE J300, the Engine Oil Viscosity Classification Surface Vehicle Standard. The purpose of the Standard is to define engine lubricating oils “in rheological terms only.” There are four categories of oil viscosity measurements that affect engine operation:

1. high temperature, high shear rate (HTHS) viscosity that controls oil film thickness in bearings,
2. low temperature, high shear rate viscosity that relates to engine startability,

3. low temperature, low shear rate viscosity that relates to oil pumpability, and
4. high shear rate viscometric effects that influence fuel economy.

Other vitally important properties of the oil such as heat dissipation, deposit/sludge control, resistance to oxidative/thermal degradation, etc. are outside the scope of J300. As vehicle engines have evolved over the years, so have the technical requirements of engine lubricants changed to address a variety of viscometric issues identified by original equipment manufacturers (OEMs). Some examples of problems addressed by the Task Force include low-temperature engine startability, the need to ensure adequate oil supply throughout the engine in cold weather, and high temperature bearing wear protection.

At various times in its history, SAE convened Open Forums to address OEM requests for improvements in lubricant performance. On April 12, 2005 an Open Forum was held in conjunction with the SAE World Congress, "How Should GF-5 Fuel Economy be Defined?" On October 25, 2005, an SAE Open Forum entitled "The Future of the SAE J300 Engine Oil Viscosity Classification System" was held in San Antonio and included formal presentations by OEMs, base stock manufacturers and additive companies. EOVC chairman Andy Jackson reviewed the current classification system and suggested a number of ways that it might be modified to offer a more rational basis for viscosity ranges. Several presentations anticipated future needs for oils with HTHS values below 2.6 mPa·s, in response to engine designers' continuous quest to improve fuel economy. Several oil companies noted that the advent of new high viscosity index (VI), low volatility base stocks could facilitate the formulation of lower HTHS viscosity fluids in the future, and SAE J300 should not be an obstacle to their use.

Development History of HTHS Viscosity Requirements in SAE J300

High temperature viscosity limits within the SAE J300 classification were for many years defined by kinematic viscosity at a defined temperature - most recently 100°C. However, by the mid-1970's there was growing recognition that a rheological measurement more relevant to engine operation was needed. Following a 1977 request by SAE, ASTM Subcommittee 7 established a task force to develop appropriate high temperature, high shear viscometric techniques and understand their relevance to engine operation. This culminated in a 1985 ASTM publication which summarized the technical literature on HTHS viscosity [2]. During this period, the three commonly used HTHS methods were developed and refined: the Tapered Bearing Simulator (TBS, D4683), Tapered Plug Viscometer (TPV, D4741) and High-Pressure Capillary Viscometers (D4624, later D5481). A technical symposium in 1988 summarized

much of the ASTM and industry work in terms of both engine studies and HTHS measurement techniques [3]. While these studies noted the relationship between fuel economy and high shear viscosity (at the appropriate engine operating temperature) [3], the concern from a specification standpoint was oil film thickness and its relation to durability; and much effort was spent to correlate HTHS and minimum oil film thickness (MOFT). In fact, in a preamble to STP 1068 technical papers, Z. Holubec (then ASTM D02.07 Chair) noted that "there are those in the industry who refuse to believe that such [engine] failures are likely to occur in future engine designs if HTHS oil viscosity of lubricants is not defined" [3]. It was these MOFT considerations in the journal bearing areas of the engine that drove the focus on 150°C measuring temperatures at a shear rate of 10⁶ sec⁻¹.

An example of some of the MOFT-HTHS correlation work from the engine studies is shown in Figure 1 [4].

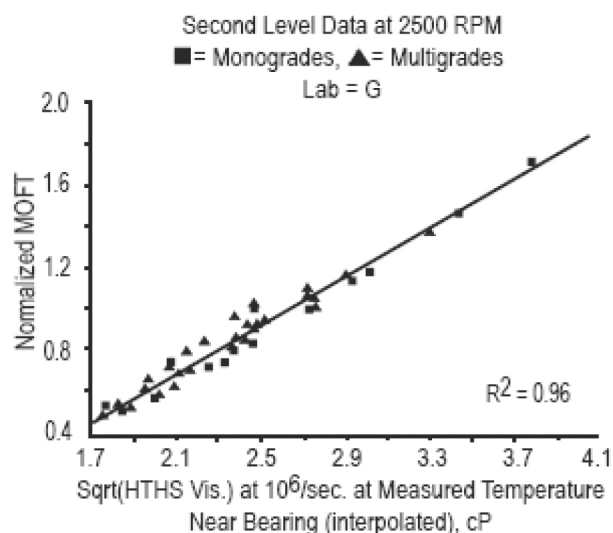


Figure 1. Correlation of normalized minimum oil film thickness to (HTHS viscosity)^{0.5} at measured temperature [4]. Copyright SAE International Reprinted with permission from SAE paper 902064.

Other studies utilized a range of engine oils formulated with a single performance additive package and measured the effects of very low HTHS viscosities on main and connecting rod bearing wear in field testing; high wear was observed below some threshold HTHS viscosity (Fig. 2, 3) [5, 6]. Additional work demonstrated that a similar step change in wear can be observed in piston ring and cam face wear [7].

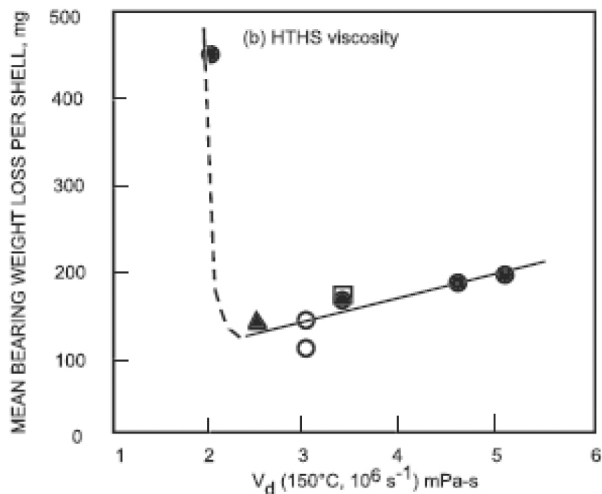


Figure 2a. Dependence of big-end bearing weight loss on viscosity [5]. Copyright SAE International Reprinted with permission front SAE paper 892154.

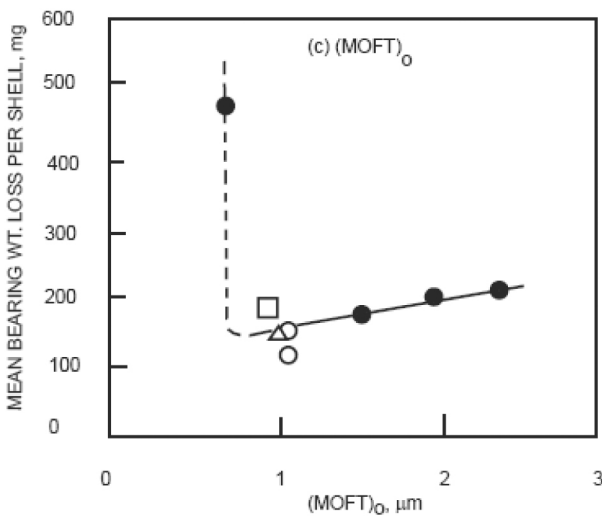


Figure 2b. Dependence of big-end bearing weight loss on minimum oil film thickness [5]. Copyright SAE International Reprinted with permission from SAE paper 892154.

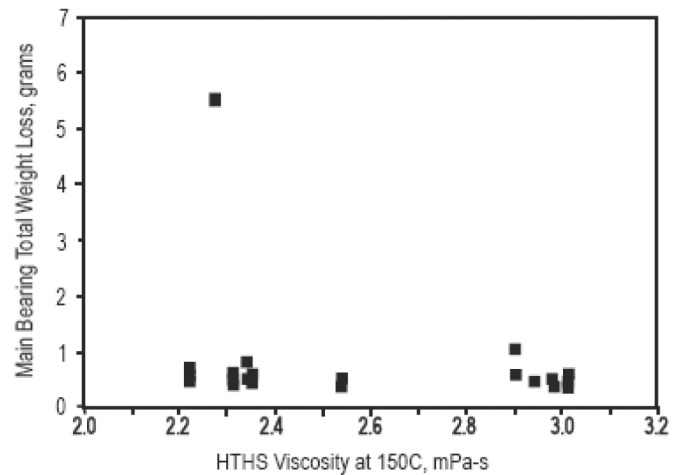


Figure 3a. Main bearing wear as a function of HTHS viscosity at 150°C from a controlled field test [6]. Copyright SAE International. Reprinted with permission front SAE paper 922342.

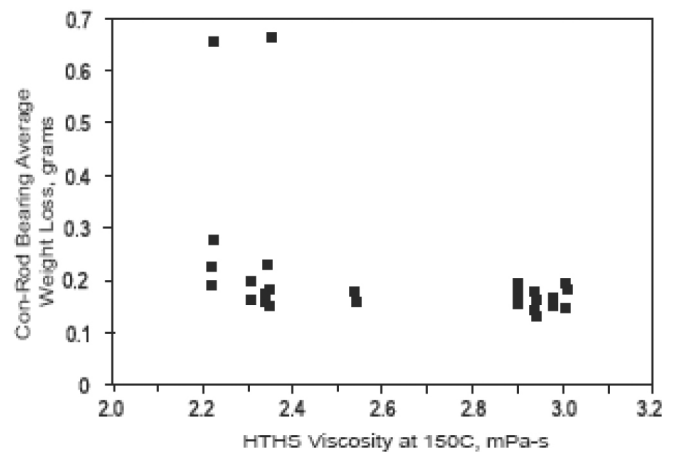


Figure 3b. Connecting rod bearing wear as a function of HTHS viscosity at 150°C from a controlled field test [6]. Copyright SAE International. Reprinted with permission front SAE paper 922342.

The first reference to HTHS viscosity in J300 appeared in the June 1987 version and was limited to comments on instrumental methods and OEM limits with a recommendation that formulators consider these during oil development [8]. These comments were further expanded with additional references in the June 1989 version of J300, but it was not until the February, 1992 Standard that HTHS limits were explicitly defined, the initial approach being to associate them with the 'W' grade classification.

Table 1. HTHS Limits Introduced with SAE J300 FEB92

SAE Viscosity Grade	Low-Temperature ("C) Cranking Viscosity", cP	Low Temperature ("C) Pumping Viscosity", cP	Kinematic Viscosity ⁴ (cSt) at 100°C		High-Temperature High-Shear Viscosity ^{5,6} (cP) at 150°C and 10 ⁶ s ⁻¹
	Max	Max with no Yield Stress	Min	Max	Min
0W	3,250 at -30	30,000 at -35	3.8	---	2.4
5W	3,500 at -25	30,000 at -30	3.8	---	2.9
10W	3,500 at -20	30,000 at -25	4.1	---	2.9
15W	3,500 at -15	30,000 at -20	5.6	---	3.7
20W	4,500 at -10	30,000 at -15	5.6	---	3.7
25W	6,000 at -5	30,000 at -10	9.3	---	3.7
20	---	---	5.6	< 9.3	---
30	---	---	9.3	< 12.6	---
40	---	---	12.5	< 16.3	---
50	---	---	16.3	< 21.9	---
60	---	---	21.9	< 26.1	---

These limits would later be revised to associate them to the non-W grade classification (with some consideration for differentiated limits with multigrade 40's depending upon their W grade.

Table 2. HTHS Limits Introduced with SAE J300 MAR93

SAE Viscosity Grade	Low-Temperature ("C) Cranking Viscosity", cP	Low Temperature ("C) Pumping Viscosity", cP	Kinematic Viscosity ⁴ (cSt) at 100°C		High-Temperature High-Shear Viscosity ^{5,6} (cP) at 150°C and 10 ⁶ s ⁻¹
	Max	Max with no Yield Stress	Min	Max	Min
0W	3,250 at -30	30,000 at -35	3.8	---	---
5W	3,500 at -25	30,000 at -30	3.8	---	---
10W	3,500 at -20	30,000 at -25	4.1	---	---
15W	3,500 at -15	30,000 at -20	5.6	---	---
20W	4,500 at -10	30,000 at -15	5.6	---	---
25W	6,000 at -5	30,000 at -10	9.3	---	---
20	---	---	5.6	< 9.3	2.6
30	---	---	9.3	< 12.6	2.9
40	---	---	12.5	< 16.3	2.9 (0W- / 5W- / 10W-40)
40	---	---	12.5	< 16.3	3.7 (15W- / 20W- / 25W-40, 40)
50	---	---	16.3	< 21.9	3.7
60	---	---	21.9	< 26.1	3.7

These HTHS limits remained unchanged until the J300 NOV2007 version which adjusted the 0W/5W/10W-40 minimum from 2.9 to 3.5 mPa·s.

As mentioned previously, various studies have demonstrated correlations between engine fuel economy and HTHS viscosity of the lubricant [12, 13, 14]. In general, correlation is greatest when the viscosity is measured at a temperature typical of the bulk oil during the fuel economy test cycle (e.g. 70 ~ 100°C). In fact the strong correlation between 100°C HTHS and fuel economy in the new Seq. VID test has led to the adoption of read-across rules based upon the HTHS viscosity of the original oil and the read-across fluid at this temperature [15]. The viscosity at which this correlation breaks down in a particular engine needs to be examined by the respective engine designer to define an optimal HTHS viscosity for fuel economy performance.

SAE WORKING GROUP MISSION AND MEMBERSHIP

The scope and objectives of the SAE Low Viscosity Grade Working Group were established by the EOVC Task Force as follows: "With OEM guidance, develop options for extending

the SAE J300 classification system to oils with HTHS (150°C) viscosities below 2.6 mPa·s. This will require additions/modifications to the kinematic viscosity classifications."

Members of the Working Group are listed in the [Appendix](#).

Straw man Proposal for SAE Viscosity Grades below SAE 20

The Working Group felt that a reasonable starting position for creating new viscosity grades below SAE 20 would be to define HTHS in increments of 0.3 mPa·s without initially imposing kinematic viscosity limits narrower than the current SAE 20 grade. See [Table 3](#) below. This "straw man" proposal was mailed on November 6, 2009 to representatives of the International Lubricants Standardization and Approval Committee (ILSA) and the European Automobile Manufacturers Association (ACEA) to solicit feedback from their members.

Table 3. Straw man proposal for new SAE viscosity grades below SAE 20. KV = kinematic viscosity at 100°C.

Proposed SAE Grade	HTHS min	KV min	KV max
20 (existing grade)	2.6	5.6	<9.3
15	2.3	5.6	<9.3
10	2.0	5.6	<9.3
5	1.7	5.6	<9.3

Since the new ranges share the same kinematic viscosity limits, they were meant to be distinguished solely on the basis of HTHS viscosity.

To date, feedback to the proposed straw man has been mixed. Toyota Motor Corp and Honda Motor Corp have indicated support for the proposed limits and the activities of this Working Group. Both companies would like to see a formal system in place to allow common understanding of the HTHS requirements for these low viscosity fluids. Ford Motor Co. has responded that they see no current/near term need for viscosity grades below SAE 20 [9]. They have expressed concerns about the potential to label an oil as meeting more than one viscosity grade, and would prefer to have discrete ranges in both HTHS and kinematic viscosity. Both Ford and Chrysler have commented in Work Group meetings that they want to protect the integrity of the current SAE 20 viscosity grade classification as both manufacturers recommend SAE 5W-20 oils for many of their engines.

ACEA responded that they see no need for changes to SAE J300 [10], and have similar concerns about potential viscosity grade overlap in the system being proposed. ATIEL