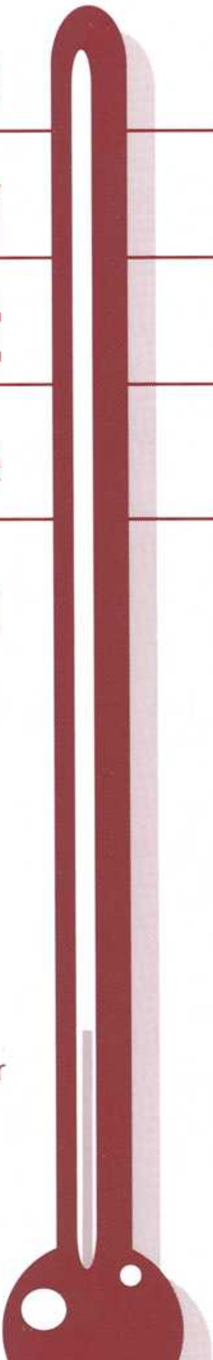
# Low Temperature Lubricant Rheology Measurement and Relevance to Engine Operation



Robert B. Rhodes editor

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# *Low Temperature Lubricant Rheology Measurement and Relevance to Engine Operation*

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# Foreword

This publication, *Low Temperature Lubricant Rheology Measurement and Relevance to Engine Operation*, contains papers presented at the symposium of the same name held in Austin, TX on 10 Dec., 1991. The symposium was sponsored by ASTM Committee D-2 on Petroleum Products and Lubricants and its Subcommittee D02.07 on Lubricant Flow Properties. Robert B. Rhodes of the Shell Development Company in Houston, TX presided as symposium co-chairman and is the editor of the resulting publication.

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# OVERVIEW

An engine oil must lubricate the engine at all ambient temperatures under which it is operated. Recent history has shown the low-temperature environment to be most critical, for it can alter the rheological properties of lubricants so as to provoke catastrophic engine failures. While test methods and specifications have been implemented to prevent this from happening, recent technological changes to the engine lead us to question whether the present rheological safeguards are still applicable. This Special Technical Publication has been published as a result of a symposium on Low Temperature Lubricant Rheology Measurement and Relevance to Engine Operation, held in Austin, Texas in 1991. The symposium was the outgrowth of work within ASTM Subcommittee D02.07 on Lubricant Flow Properties, a subcommittee of ASTM Committee D-2 on Petroleum Products and Lubricants.

The symposium was undertaken to accomplish three things. First, it would offer a chronology of developments regarding the low-temperature rheological techniques and specifications that apply to the low-temperature cranking and pumping characterisitcs of engine oils. Second, it would focus on the technological changes that have occurred since the completion of the last round of low-temperature engine and bench test studies. Third, it would bring to light new information that would help determine whether the cranking, starting, and pumping needs of present-day engines are adequately served. Within this Special Technical Publication, the reader will be exposed to each of these areas by key contributors to our present knowledge.

At the beginning of the 1980's, unusual winter weather brought about disruptions in the driving habits of a number of North American car owners. Cold weather and slow, gradual cooling conditions combined to create geographical pockets that were eventually identified by a high incidence of engine failures. Presumably, some engine failures occurred because the engines did not start, but the failures that were highly publicized occurred because some engines **did** start — then failed! Unfortunately, the oils within the failing engines were so gelled and so viscous that pumping of the oil was impossible, and rapid engine damage and failure occurred. These oils caused failure because of wax precipitation, which was induced by the unusual cooling patterns that were characteristic of that period.

Preventive measures were put into place, however, and today, after a substantial body of work within ASTM, there are three new or newly-revised ASTM test methods that relate to engine cranking or pumping. These test methods are discussed in several papers included within this publication. Also, the Society of Automotive Engineers (SAE) revised SAE J300, the Engine Oil Viscosity Classification Standard, to provide a measure of protection against pumping failures with SAE W-grade oils. Pumping viscosity, and yield stress, are measures of an oil's ability to flow to the engine oil pump and provide adequate oil pressure during the initial stages of operation. Cranking viscosity has been found to correlate with engine speeds developed during low-temperature cranking of engines. A margin of safety was defined in SAE J300 by placing the limits on pumping viscosity and yield stress five degrees (Celsius) lower than those for cranking viscosity, the premise being that if an engine cranks, the oil will be fluid enough to flow after the engine starts.

At this writing, the system seems to be working well, and there have been no recent reports of pumpability field failures. But consider this: the engines and the engine oils that were used to establish the cranking and pumping viscosity limits in SAE J300 are now 10 to 30 years old. Neither the engines nor the engine oils used in those studies have been in production for a long, long time. The present system and test methods will protect old equipment, but what about modern equipment?

As discussed in this publication, there has been a tremendous change in engine design over the last decade. Spurred by fuel economy and emissions requirements, the modern "low-friction", fuel injected, electronic controlled engines start more reliably than their predecessors. The modern gasoline engines may start at a much lower temperature than engines of the 1960–1980 era; alternatively, it can be said that the modern engine may start with oils having much higher cranking viscosities than heretofore. The owner manuals provided with today's gasoline-fueled vehicles recommend the use of SAE 5W–30 oils, which have lower cranking viscosities at a given temperature, and therefore permit starting at even lower temperatures than the SAE 10W–30 and SAE 10W–40 multigrades that were in predominant use ten years ago.

But engine oil composition has also changed. The use of friction modifiers is likely to make starting easier. And there has also been an evolutionary change in lubricant additive technology and in base oil processing, which is also reviewed here. New methods to dewax base stock have become prevalent. Such processes may alter the composition of the residual wax that is not removed in the dewaxing process. Additive technology can sometimes be particularly sensitive to residual wax precursors unless great care is taken in the selection of pour point depressant. So while a batch of a modern engine oil may meet pumpability requirements handily on a given day, a change in processing conditions, or in crude source may result in a batch with different pumpability characteristics on another day, unless composition is carefully monitored at the point of origin.

Also, more severe engine test requirements and new testing restrictions have resulted in lubricants which contain higher concentrations of lubricant additives. Since these additives contribute to cranking viscosity, it has become more difficult for some lubricant formulators to meet present cranking viscosity requirements using conventional base stocks. Higher cranking viscosity limits would provide a welcome relief and might be directionally valid if modern engines start at, or below, the temperatures where pumpability limits are presently defined by SAE J300. However, slower, more difficult starting equates to higher emissions levels.

The third objective of this symposium was to obtain new data which would give guidance as to whether new studies are needed with regard to the low-temperature starting and pumping characteristics of gasoline and diesel engines. One presentation provided some good news regarding diesel engine performance. Using three types of diesel engines and twenty-one new and used multigrade oil formulations, no evidence of pumpability problems were discovered. (This paper is not included in this STP, but is referenced as follows: A. G. Alexander, C. J. May, and C. R. Smith," Factors Affecting Pumpability in Heavy Duty Diesel Truck Engines at Low

Ambient Temperatures," SAE Paper 912337, Society of Automotive Engineers, Toronto, Canada, 1991.)

However, as described in another report included herein, certain 1984–1985 vintage passenger cars which contain SAE 10W–40 multigrades could be started at temperatures as low as −25°C, which is 5°C below the temperature where cranking viscosity is defined for a 10W grade, and which coincides with the temperature where the pumping viscosity is determined. Similar conclusions resulted from certain diesel engine studies. Thus, it appears that the 5°C margin between starting and pumping viscosity may not exist. There is also some criticism of the criteria that has been used to characterize engine oil pumpability. One author reported that the critical shear stresses at the engine pump inlet were conservatively approximated by measurements obtained using the ASTM test method which measures pumping viscosity, but other authors concluded that the criteria used to approximate engine pumpability should include a measurement that correlates with the time to lubricate other critical oiling locations.

These papers will not only bring the reader up to date on the measurement of low-temperature rheology tests for engine lubricants, but they will also call attention to concerns about the use of present test methods to portend lubricant engine performance. To the extent that our correlations are based on the technology of the past and not the present, the SAE J300 Standard may not offer engines sufficient cold-weather protection. Of primary importance is whether different cranking viscosity limits need to be employed to protect modern engines. Also, what are the pumping characteristics of these engines and are the present rheology test methods sufficient for oil characterization?

There has been a rapid response to the symposium disclosures. The SAE requested on May 29, 1992, that ASTM carry out a program to redefine the low-temperature operational characteristics of new engines and new lubricants, and on June 16, 1992, the Task Force on Low-temperature Engine Performance was formed within ASTM Subcommittee D02.07 to act on this request. In deference to the vagaries of the weather, it was the right thing to do.

I wish to take this opportunity to thank Dr. Z. M. Holubec of Lubrizol, the chairman of Subcommittee 7, for suggesting that this symposium be held, Dr. H. Shaub of Exxon Research and Engineering, for acting as co-chairman and moderator, and for the authors and ASTM personnel that have made this publication possible.

*R. B. Rhodes*

Shell Development Company,
Houston, TX 77070; symposium
organizer, co-chairman and editor

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