Understanding the SAE Motor Oil Viscosity Standard

What is motor oil viscosity?

Simply put viscosity is a physical property of a fluid or gas that reflects it's tendency to flow. We commonly refer to high viscosity fluids as being "thick" and low viscosity fluids as being "thin". It's an important property of a motor oil because changes in viscosity affect the ability of the oil to lubricate and protect the moving parts of an internal combustion engine. If the oil is too thin the oil pump cannot maintain enough pressure to circulate it and the oil will not withstand the forces that form between moving parts. The metal parts will rub against each other and wear out or fail prematurely from lack of proper lubrication. Conversely, if the oil is too thick the oil pump will again have problems circulating the oil and it will be too thick to penetrate into the tiny openings between moving parts. The result is the same – premature wear and failure. So it's important that the viscosity of a motor oil be a proper balance between too thin and too thick.

How is viscosity measured?

There are two units of measure commonly used for viscosity of fluids. The basic unit is the centipoise (cP or mPa·s). This unit describes the movement of the different layers of a fluid when subjected to a horizontal force. It is commonly known as dynamic or simple viscosity. Another unit of viscosity is the centistoke (cSt or mm^2/s). This unit describes the ease with which a fluid moves under the force of gravity and is the form of viscosity with which we are most commonly familiar. This form of viscosity is known as kinematic viscosity.

One of the oldest and most common methods for measuring kinematic viscosity is an apparatus called the capillary viscometer (see picture). This apparatus is a precisely graduated glass tube. A small quantity of the fluid to be tested is placed into the top of the tube and held there with air pressure. The pressure is then released and the length of time it takes for the fluid to move to a graduated mark on the other end of the tube is measured. Higher viscosity fluids move slower, lower viscosity fluids move faster. The viscometer is usually immersed in a temperature controlled bath during the test so that the measurement is calibrated to a specific fluid temperature.

What do the SAE numbers on a container of motor oil mean?

SAE J300 Motor Oil Specification (ca. 1911)	
SAE Grade	**Flow Rate @100°C**
10	<= 14 seconds
20	15 to 24 seconds
30	25 to 34 seconds
40	35 to 44 seconds
50	>= 45 seconds

To properly answer that question a bit of history is required. Motor oil is like every other fluid in that its viscosity varies with temperature and pressure. Since the temperature and pressure conditions under which most automobile engines operate are reasonably constrained the viscosity requirements for a motor oil can be quantified and standardized. In the United States, the organization that sets the standards for performance of motor oils is the Society of Automotive Engineers (SAE). In 1911 the SAE published the first version of their standard (SAE J300) for motor oil viscosity. The SAE wanted a system that reflected the suitability of an oil for use as an engine lubricant and was easy for the consumer to understand. Their initial specification defined five different ***numbered grades*** for motor oil (10, 20, 30, 40, and 50). The grades were based on flow rates measured at 210° F (100° C) as shown in the table to the left. Very shortly the original specification was updated to use a standard scientific unit of viscosity (cSt) instead of time. By 1926 there were six grades of oil defined (SAE 10 through SAE 60) specified by viscosities measured at two temperatures - 130° F (55° C) and 212° F (100°C). Over time further shortcomings in this system were identified and it has been amended numerous times.

A major change was made in 1952 when the original set of grade designations was augmented with the addition of a set of winter ("W") grade designations (10W, 15W, 20W, 25W, 30W) which were specified by viscosity measured at 0° F. This change was instituted to address problems with cold weather oil performance. Engineers and consumers alike had come to realize that the existing grade specification did not adequately describe the cold weather nature of existing motor oils. At freezing temperatures an oil meeting specification SAE 20 refined from aromatic black Gulf crude was much thicker than an SAE 20 refined from light amber Pennsylvania crude. Engineers began to measure this difference in behavior with a viscosity ratio metric called the Viscosity Index (VI). The Gulf crude based oils which had lower indices did not provide the same level of engine protection in winter conditions as Pennsylvania crude based oils which had higher indices. This led to the well deserved reputations for superior cold weather protection of brands such as Pennzoil and Quaker State. Now engine manufacturer's began to specify "W" grades for winter use.

Advances in petrochemical engineering soon led to the development of chemical additives (viscosity enhancers) which when combined with a motor oil increased it's viscosity index making it possible for a single oil to meet both the low temperature and the high temperature grade specifications. The molecules of these additives unwind as the temperature of the oil increases and slow down the rate at which the oil's viscosity decreases. Additive enhanced oils which met both warm and cold temperature specifications became known as ***multi-grade*** oils. A major drawback to early multi-grade oils was oxidation of the viscosity enhancers during normal engine operation. As they oxidized they left harmful deposits inside the engine and their ability to maintain viscosity at higher temperatures degraded – simply put they were dirty and they wore out. Subsequent research and development has significantly reduced but not fully eliminated these problems. Development of fully synthetic motor oils has however produced multi-grade oils that do not incorporate viscosity enhancers. These oils are produced by breaking hydrocarbon molecules (typically ethylene gas) apart and recombining the component pieces into oils with entirely new molecular structures. These entirely man-made synthetic oils have extremely high viscosity indices. The downside to synthetic oils is their expense – they are expensive to produce and cost 3X or more as much as conventional oils. That expense is offset somewhat by the fact that they are very clean running and have extended life spans.

As the popularity and use of multi-grade oils increased the SAE identified yet another problem with the J300 specification. Multi-grade and single grade oils had very different viscosity properties when constricted at high pressures and temperatures between moving parts inside an engine. Some multi-grades suffered severe viscosity breakdown under these conditions which led to premature engine failures. So in the early 1970's another major change to the J300 high temperature specification was made with the addition of a high shear viscosity requirement to be measured at 150° C. This specification ensured that multi-grade oils meeting the high temperature specification would provide the same level of protection as their single grade counterparts under these very demanding conditions found in newer high performance engines.

More recently (about 20 years ago) there were several outbreaks of catastrophic engine failures in both the USA and Europe due to unusually cold weather. Some engine oils thickened and gelled in these conditions. Engines would start but their pumping systems were incapable of pulling the cold oil out of the oil pans. The result was a rash of engine failures, warranty claims, and motor oil recalls. Extremely low temperatures are not necessarily required to produce gelation. Depending on the rate at which the oil is cooled gelation may occur at higher temperatures . To address this problem the J300 cold weather specification was modified to require cold temperature pumping tests. These tests simulate the slow cooling of the oil over the space of several days to subfreezing temperatures. After the oil has attained the required test temperature it is tested in a special test apparatus, the Cold Cranking Simulator (CCS). The table below shows the current (as of 1999) requirements of J300 which incorporate this change as well as adding grades 0W and 5W to the cold temperature standard.

SAE J300 (1999) Motor Oil Grades- Low Temperature Specifications				
	dynamic viscosity (mPa·s)			
Grade Designation	**Cranking Maximum**	**Temperature (°C)**	**Pumping Maximum**	**Temperature (°C)**
0W	6,200	-35	60,000	-40
5W	6,600	-30	60,000	-35
10W	7,000	-25	60,000	-30
15W	7,000	-20	60,000	-25
20W	9,500	-15	60,000	-20
25W	13,000	-10	60,000	-15

SAE J300 (1999) Motor Oil Grades - High Temperature Specifications		
Grade Designation	**kinematic viscosity (cSt) low shear rate at 100 °C**	**dynamic viscosity (mPa·s) high shear rate at 150 °C**
20	5.6 - 9.3	>2.6
30	9.3 - 12.5	>2.9
40	12.5 - 16.3	>2.9[1]
40	12.5 - 16.3	>3.7[2]
50	16.3 - 21.9	>3.7
60	21.9 - 26.1	>3.7

[1] 0W-40, 5W-40, 10W-40
[2] 15W-40, 20W-40, 25W-40
Source: Society of Automotive Engineers (SAE), December 1999

<u>Example:</u> Grade 10W40

- From the top half of the chart (grade 10W) this oil will have a cranking viscosity no greater than 7,000 mPa·s in a cold engine crankcase even if its temperature should drop to -25 °C on a cold winter night and a maximum pumping viscosity of 60,000 mPa·s .
- From the bottom half of the chart (grade 40) it will also have a kinematic viscosity in the range 12.5-16.3 cSt at 100° C and a high shear viscosity no less than 2.9 mPa·s in the high pressure parts of an engine very near the point of overheating (150 °C).

As you can see from the table each grade is defined by multiple viscosity tests. The cold temperature standard (W grades) specifies **maximum** cold temperature viscosities which are measured using mechanical pumping and cranking tests and conducted using apparatus like the Cold Cranking Simulator. This is to ensure that the oils meeting this standard will all flow readily on cold startup and reach moving parts as quickly as possible. The warm temperature standard specifies **minimum** hot temperature viscosities and are tested using apparatus like the capillary viscometer. This is to ensure that oils meeting this standard will all exhibit proper lubricating properties under the high pressures and temperatures found at normal engine operating conditions.

Which is the best grade oil for use in my motor?

Put that question to a group of “knowledgeable” motor heads and the fur will fly. Pronouncements of doom and dire consequences will abound, usually supported by half truths, urban myths, and anecdotal experiences giving rise to a general atmosphere of fear, uncertainty, and doubt (FUD). A good understanding of the information presented above will help dispel much of that FUD and aid you in making a well informed choice. In general you are best served to simply follow the recommendations of the engine manufacturer. But there are times when that may not be practical or wise. The manufacturer’s recommendation is based on the assumption that the motor is in new or close to new condition and is being operated in a typical environment. It is also based on the SAE standards in effect at the time the recommendation is issued. As we’ve seen the SAE standard has changed tremendously over the last 100 years and tremendous advances in motor oil performance have been realized. So a 50 or even 25 year old grade recommendation might not be the best choice given current standards and/or oils. And if your motor is badly worn or operated in unusually harsh or demanding environments that may alter the grade requirements as well.

How can I evaluate the suitability of different grades of oil for use in my particular situation?

Another question that spawns an over abundance of FUD. A good place to start is by using the 1999 J300 table above in conjunction with the engine manufacturer’s recommendations. The table specifies the upper and lower bounds of performance required of today’s oils. But it doesn’t help much with performance issues in that big gray area in between. For more detailed data on a specific oil you need the oil manufacturer’s data sheets. These datasheets are readily available from most manufacturer’s web sites and contain some of the actual SAE test results for that specific product. Let’s consider a common situation as an example and see how it might be analyzed.

Your Situation

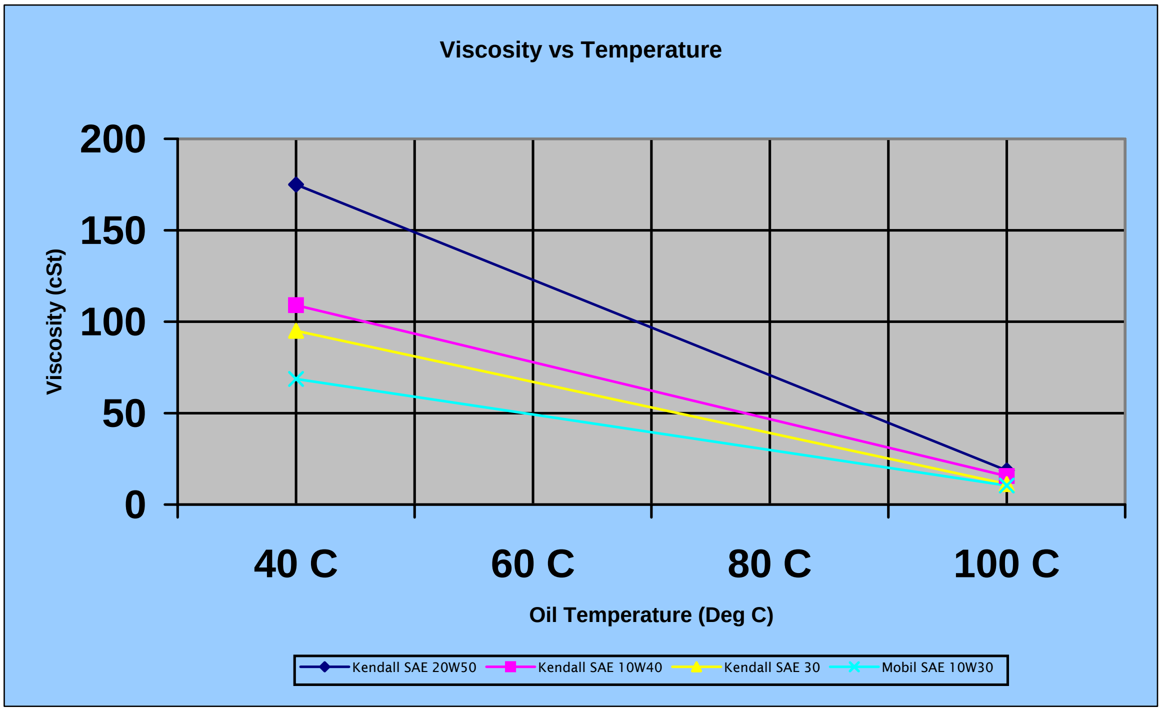
You have a newly rebuilt 50 year old antique motor where the manufacturer recommended SAE 30 for summer use and SAE 20 for winter use

Your Question

Is there a modern multi-grade suitable for year round use instead

Your Analysis

While the SAE standards have changed over the years the minimum standards for each grade have only become more demanding. So if a 50 year old SAE 30 was recommended for summer use in a new motor it’s pretty safe to assume that a modern SAE 30 meets or exceeds the original warm weather requirements. And if an SAE 20 warm weather grade was specified for winter use it's pretty safe to assume that any multi-grade with a winter rating meets or exceeds the original recommendation. From the J300 table you know that an SAE 10W30 has the same high temperature viscosity rating as an SAE 30 but your old motor never gets above 70°C (160° F) and you're afraid the SAE 10W30 won't have the same viscosity at this lower temperature as the originally specified SAE 30 did. Plus you've heard that a 10W30 is ***really*** an SAE 10 oil (which BTW doesn't currently exist) with additives and that worries you. You're not an automotive engineer and you don't know if it really matters so you want to match as close as possible the original performance specification. Probably a wise decision. You decide you can live with the additive problems of conventional oils since you change your oil on a regular basis and you can't afford the expense of a full synthetic. You get the data sheets for several different products and plot their viscosities versus temperature on a graph as shown below. The data sheets don't have complete viscosity curves in them but they do give kinematic viscosities at 40° C (roughly 104° F) and 100° C (212° F). You decide to approximate the in between values using straight lines through the 40° C and 100° C data points given.



You randomly choose Kendall GT-1 SAE 30 as your base line oil. It's a single grade just like originally specified and you plot its viscosity on the graph. Then you choose Mobil 5000 SAE 10W30 as a possible multi-grade alternative (Kendall doesn't make a conventional 10W30). You plot it's viscosity numbers on the graph and what you discover is it has a slightly lower viscosity than the SAE 30 through out the entire temperature range. It's not dramatic but it is lower. Maybe not a good choice – it worries you. Kendall does however make a 10W40 in the GT-1 line and you plot the data for it as well. That shows it has a viscosity slightly higher than the single grade. Again, not dramatic but a bit higher across the entire temperature band and slightly exceeds the performance of the SAE 30 single grade originally specified. That's a total surprise and not at all what you expected! This looks like a very good choice – not to thick – not too thin – just right. Out of curiosity more than anything else you plot the data for Kendall's 20W50 GT-1 oil. Higher still – maybe too high - but you file the info away for future use. It might be a good choice a few years down the road if and when your new rebuild gets a bit worn and starts loosing oil pressure. Satisfied you have all the info you need you go shopping.