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Performance Chemicals

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Viscosity Index Improvers For Fuel-saving Engine Oils

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With a goal of creating a sustainable society including the sustainable development goals (SDGs), environmental measures have been proceeded with to combat global warming and efforts to reduce carbon dioxide (CO_2) emissions and save energy are now being made not only by businesses but also at home. The total emissions of greenhouse gases in Japan have gradually been decreasing since its peak in 2013[1]. Improvement in fuel efficiency is an important challenge because CO_2 emissions from automobiles account for about 20% of the total emissions. For the fuel-economy criteria, targets will be discussed and coordinated in a subcommittee organized jointly by the Ministry of Land, Infrastructure and Transport and the Ministry of Economy, Trade and Industry. It is expected that the fuel-economy criterion for passenger vehicles in total for each company will be raised to 20.3 km/ℓ by 2020 (17.0 km/ℓ in 2015). In response to this, measures such as reduction in weight of vehicles, increase in engine combustion efficiency, and shift to hybrids and electric vehicles have been underway. Enhancing the performance of lubricating oils is also one of the measures. What significantly contributes to the efforts to enhance the performance of lubricating oils is viscosity index improvers (hereinafter abbreviated as VIIs). This report describes types, trend, and action mechanism of VIIs and introduces our high-performance VII series for engine oils "ACLUBE."

What is a VII?

Lubricating oils such as engine oils and oils for driving systems of automobiles are essential to reduction in friction for smooth movement of machines. Among the performance requirements to express the function, viscosity is an important property. Lubricating oils are used in a wide temperature range from low to high temperatures (approximately -30 to 150°C). In general, viscosity of a liquid is likely to be low at high temperatures and high at low temperatures; however, viscosity of a lubricating oil is expected not to vary extremely depending on temperatures. For example, when viscosity of the lubricating oil is too low in an environment where temperature of the lubricating oil gets high, including during driving for a long time in summer, a thinner layer of the lubricating oil formed on the metal may lead to reduction in lubricity, resulting in problems such as wear and seizing. On the other hand, when viscosity of the lubricating oil is too high at low temperatures such as when starting a vehicle in winter, viscosity resistance contributes to a great loss of energy, resulting in reduced fuel economy.

To minimize these variations in viscosity depending on temperatures, a VII is added. The smaller the variations in viscosity are (the higher the viscosity index is), the higher the effect of VII is for improving fuel economy.

Types of VIIs

Based on their chemical compositions, VIIs are classified into the following two groups: olefin copolymer (OCP)-based improvers and polymethacrylate (PMA)-based improvers. OCP-based improvers come in the types shown in **Table 1**. PMA-based improvers improve viscosity index more effectively than OCP-based improvers, that is, PMA-based improvers are highly effective for improving fuel economy. PMA-based improvers are used more often than ever before both in Japan and overseas, followed by an increase in global efforts to reduce environmental loads in recent years.

Trend of VIIs for engine oils

Engine oils are mineral oils or synthetic oils called base oils, containing various additives. They play various roles such as reducing friction produced by reciprocating motion of the piston, cleaning the inside of the engine, and keeping the vaporizing chamber airtight. Performance of engine oils are classified based on the viscosity classification defined by the Society of Automotive Engineers (SAE) and the standard provided by International Lubricant

Standardization and Approval Committee (ILSAC)/American Petroleum Institute (API). In the SAE viscosity classification, the multi-grade standard showing two viscosity grades at low and high temperatures is the mainstream, allowing users themselves to select best oils for their vehicles. Many of fuel-efficient Japanese cars uses oils with the 0W-20 grade (0W shows viscosity at low temperatures and 20 shows viscosity at high temperatures; the smaller both of the numbers are, the better the fuel economy is).

The ILSAC/API standard specifies fuel saving property of each viscosity grade in the engine test. Oils that meet the specified criteria are granted certification. In response to the needs for fuel saving, the criteria were made more stringent each time this standard was revised. It is said that the lower the high-temperature high-shear viscosity (HTHS viscosity) is, the better the fuel saving property becomes; however, if the HTHS viscosity is too low, a oil film formed does not function as a cushion, resulting in increase of wear. It is required to reduce viscosity at 80 to 100°C that greatly affects fuel economy as well as to assure the minimum required high-temperature high-shear viscosity at 150°C. An additive that significantly contributes to this is VII. In the past, OCP-based improvers were dominant among VIIs for engine oils because they are inexpensive and because they meet the SAE viscosity classification standard even if the amount added is small. However, PMA-based improvers that improve viscosity index more effectively than OCP-based improvers have been used more often than ever before as the fuel saving property required by the ILSAC/API standard has become more stringent.

Functions of VIIs

The principal component of VII is an oil-soluble chain polymer with weight-average molecular weight of about 10000 to 500000. Its action mechanism uses the changing dissolved state of the oil-soluble polymer in a lubricating oil. At high temperatures, the solubility of the polymer in a lubricating oil is high and the molecular chains spread, so that viscosity of the lubricating oil can increase significantly. On the other hand, at low temperatures, the solubility of the polymer is low, and the molecular chains get coiled, so that viscosity of the lubricating oil cannot increase that much. In short, a function of VII is to retain viscosity of a lubricating oil within an appropriate range **[Figure 1]**. Degrees of variations in viscosity of a lubricating oil with temperature are indicated by the viscosity index. The higher the viscosity index is, the smaller the variation in viscosity with temperature is and the more preferable the improver is for the lubricating oil. PMA-based improvers improve fuel index effectively because their molecular chains spread and shrink extremely with temperature changes.

Performance requirements for VIIs

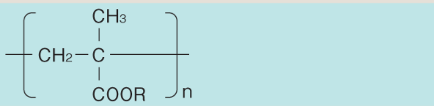
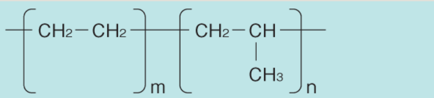
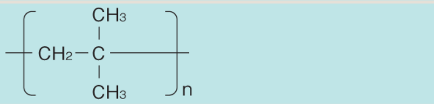
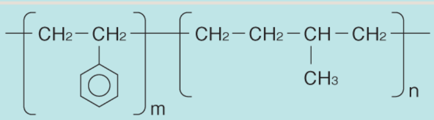
Performance required for VIIs includes performance to improve viscosity index and shear stability.

[Performance to improve viscosity index]

As described above, behavior changes in dissolved state of the polymer with temperature changes are used to improve the viscosity index and thus the viscosity index is affected by [1] solubility of the polymer in the base oil and [2] molecular weight of the polymer.

[1] Solubility in the base oil: The solubility parameter (SP value) is used as a solubility indicator. The SP value represents how easily a solute dissolves in a solvent. The smaller the difference between the SP values of the solute and solvent is, the higher the solubility of the

Table 1 **Types of VIIs**

Type of polymer		Chemical structure
Polymethacrylate (Abbreviation: PMA)		
OCP-based*	Ethylene-propylene copolymer	
OCP-based*	Polyisobutylene (Abbreviation: PIB)	
OCP-based*	Hydrogenerated styrene-isoprene copolymer (Abbreviation: SCP)	

* Olefin copolymer

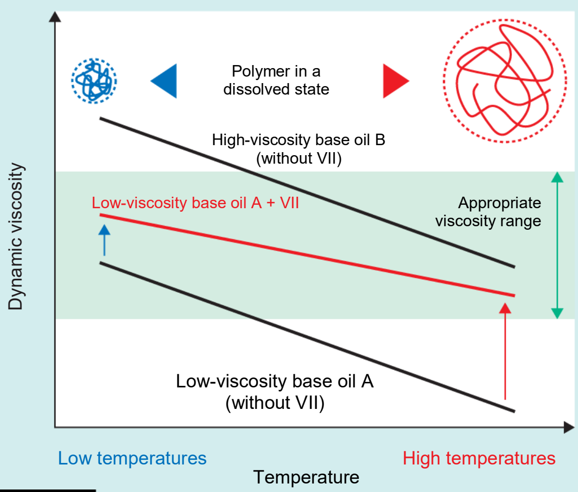


Figure 1 **Schematic diagram showing solvency action mechanism and viscosity behavior of VIIs**

solute in the solvent is. **Figure 2** shows the relation between the SP values of VIIs and the viscosity indices of lubricating oils that VIIs are added. The superiority of PMA-based improvers to OCP-based improvers in terms of improving the viscosity index is attributable to difference between the SP values of the base oil (solvent) and VII (solute). An OCP-based improver whose SP value (= about 8.2) does not differ from that of the base oil (about 8.2) is highly soluble and their molecular chains remain spread even at low temperatures. On the other hand, a PMA-based improver whose SP value (= 9.0 to 9.2) greatly differs from that of the base oil is not much soluble and thus their molecular chains shrink at low temperatures, that is, the difference in size between high and low temperatures is great, meaning that it is superior in improving the viscosity index. [2] Molecular weight: The higher the molecular weight of the polymer in VII is, the higher the viscosity index tends to be. This is because the higher the molecular weight is, the greater the change in size of the molecular chains with temperature changes is.
[Shear stability]

The molecular chains of the polymer comprising VII is gradually cut by great force (shearing force) in actual use such as mechanical pressure and friction produced in the sliding portions of a machine (rubbed portions of the piston and cylinder wall in the engine) and the engaged teeth of gears. Shear stability is especially important for lubricating oils for driving systems of automobiles that are exposed to great shearing force. Shear stability is evaluated based on the rate of reduction in viscosity of a lubricating oil due to breakage of the molecular chains. The lower the rate of reduction in viscosity is, the higher the shear stability is. The higher the molecular weight is, the larger the shear stress applied to the polymer is. The lower the molecular weight is, the better the shear stability gets but the lower the viscosity index becomes; therefore, the molecular weight is optimized based on the target performance. A polymer with low molecular weight is often used for lubricating oils for driving systems of automobiles because such oils are exposed to extremely great shearing force produced by the engagement of gears, etc. On the other hand, a polymer with high molecular weight is often used for engine oils because engine oils are exposed to smaller shearing force than that applied to lubricating oils for driving systems of automobiles.

High-performance PMA-based VIIs for engine oils, "ACLUBE V-6000" series (Latest grade)

The following explains the high-performance PMA-based VIIs for engine oils, "ACLUBE V-6000" series that are more sophisticated in improving fuel saving property than the conventional PMA-based improvers superior in improving viscosity index. The "ACLUBE V-6000" series are a polymer made by copolymerizing our original special monomer with special long-chain alkyl group that we developed with our unique technology and a conventional monomer. This polymer can dissolve in a base oil even though it shows a high SP value, which was impossible with a conventional technology. In addition, the polymer has a structure that makes it easier for VII to shrink in a low-temperature range. Therefore, the product achieves a high viscosity index while maintaining high shear stability, compared to conventional general-purpose PMA-based improvers **[Figure 3]**. Ever higher performance than that of conventional products has been achieved through optimization of the ratio of our original special

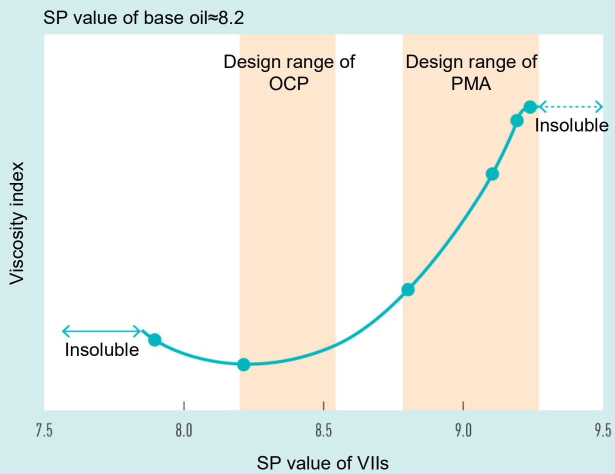


Figure 2 **Relation between the SP values of VIIs and the viscosity indices of lubricating oils**

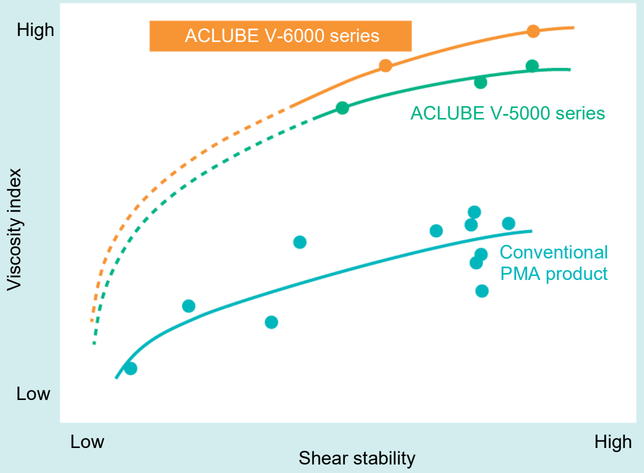


Figure 3 **Comparison of key performance between the "ACLUBE V-6000" series and conventional products**

monomer. **Table 2** shows performance of the lubricating oils containing our high-performance PMA-based VIIs for engine oils, “ACLUBE V-6000” series, and those containing conventional improvers. The performance evaluation was conducted with the dominant grade 0W-20 for Japanese cars in mind. When the HTHS viscosity of this product at 150°C is set to an assured viscosity of 2.6 mPa•s, the HTHS viscosity at 100°C is reduced by about 15% compared to that of a SCP-based conventional product with fuel saving property superior to those of other OCP-based products and by about 3% compared to that of our conventional “ACLUBE V-5000” series. The “ACLUBE V-6000” series significantly contributing to improvement in fuel economy of automobiles have been increasingly adopted in fuel-saving engine oils mostly for Japanese cars. To respond to various needs that differ depending on the type or formulation of lubricating oil used, we provide a selection of products, including those achieving cost reduction by reducing an amount to be added while maintaining performance equivalent to that of conventional products (V-6010) and those with excellent fuel saving property (V-6050). In addition, the “ACLUBE V-6000” series comply with the standard discussed later, which responds to needs for higher fuel saving property, because they have excellent fuel saving property. We also offer the “ACLUBE” series other than those for engine oils, including lubricating oils for driving systems of automobiles such as continuously variable transmission fluids (CVTF), automatic transmission fluids (ATF), and gear oils, so that we can respond to wide-ranging needs for the additives for lubricating oils for automobiles that meet more stringent requirements for shear stability and performance to improve viscosity index.

Future prospects

ILSAC has been working on a revision of the current standard (GF-5) to the next-generation standard (GF-6) that responds to needs for higher fuel saving property and will make the revision in a period from the latter half of 2020 to the first half of 2021. For this reason, importance of VIIs that contribute to improvement in fuel saving property is increasing. We will further deepen the polymer design technology, promote the development of products with higher performance, and contribute to the improvement of fuel saving property of automobiles with our high-performance products, so that we can reduce the emissions of greenhouse gases, contributing to reduction in environmental loads.

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Table 2 **Comparison of performance between the “ACLUBE V-6000” series and conventional products**

Performance item*1	Unit	0W-20 Requirements in standards	ACLUBE V-6010	ACLUBE V-6050	ACLUBE V-5130	Conventional products SCP-based
Nondispersive/dispersive	-	-	Nondispersive	Nondispersive	Dispersive	Nondispersive
Amount added	Mass %	-	7.0	12.0	11.9	-
HTHS viscosity (150°C)	mPa·s	2.6≥	2.6	2.6	2.6	2.6
HTHS viscosity (100°C)	mPa·s	-	4.9	4.6	4.7	5.6
Dynamic viscosity (100°C)	mm^2/s	5.6～9.3	8.1	8.3	7.7	8.8
Dynamic viscosity (40°C)	mm^2/s	-	32.0	33.0	30.8	43.7
Viscosity index	-	-	244	243	237	187
Cold cranking simulator (CCS) viscosity (-35°C)	mPa·s	6,200≥	5,600	5,100	5,200	6,200 <
Mini-rotary viscometer (MRV) viscosity (-40°C)	mPa·s	60,000≥	18,000	14,000	14,000	60,000 <
Yield stress*2	-	35 >	35 >	35 >	35 >	35 <
BOSCH SSI*3	-	-	28	32	25	6

*1 Base oil in package: Dynamic viscosity at 100°C=5.2 mm^2/s *2 Cold-start performance indicator
*3 Shear stability indicator (the lower the value is, the better the stability is)