Jaroslav Cerny, Ivana Vaclavickova

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SMIČNA STABILNOST MOTORNIH ULJA

Sažetak

U radu se sažimaju utjecaji na viskoznost motornoga ulja, poput smične stabilnosti modifikatora viskoznosti, udjela goriva i/ili čađe te degradacije ulja izazvane toplinskom oksidacijom. Značaj pojedinačnih vidova praćen je za nekoliko motornih ulja različitih gradacija viskoznosti cestovnim radom vozila s benzinskim motorom, kao i onih s dizelovim motorima. Trendovi promjene viskoznosti praćeni su i procjenjivani.

1. Viskoznost motornih ulja pri njihovu djelatnu korištenju

Viskoznost je jedno od temeljnih funkcionalnih svojstava motornih ulja. Mjeri se kao otpor ulja ka tečenju prilikom njegova tiskanja kroz kapilaru [1]. Viskoznost motornih ulja određuje se u tijeku njihove proizvodnje namješavanjem odgovarajućih baznih ulja i dodavanjem modifikatora viskoznosti. Uloga je modifikatora viskoznosti zgusnuti bazno ulje i povećati njegov indeks viskoznosti, kako bi se postigao željeni razred viskoznosti. U optimalnome bi slučaju svojstva viskoznosti trebala ostati stabilnima kroz čitav vijek trajanja ulja. Međutim, brojni su čimbenici koji mogu utjecati na viskoznost ulja za vrijeme njegova korištenja.

1.1 Gorivo

Benzinsko ili dizelsko gorivo u maloj je količini prisutno u gotovom svim motornim uljima u fazi njihova korištenja. Visoka razrijeđenost goriva može izazvati alarmantno smanjenje viskoznosti ulja te u iznimnim slučajevima HTHS viskoznost može pasti ispod prihvatljive razine. Škoda-Auto (član WV skupine) tvrdi kako maksimalni iznos razrijeđenosti goriva ne smije prijeći 4%, u slučaju benzinskih motora. Prekomjerna je razrijeđenost goriva uglavnom izazvana korištenjem neprimjerena goriva i/ili kvarom sustava ubrizgavanja [2]. U nekim slučajevima, često hladno pokretanje motora također može uvelike pridonijeti razrijeđenosti goriva, osobito u smislu povećanja količine lakih benzinskih spojeva, koji se inače isparavaju pri radnim temperaturama motora.

1.2 Čađa

Čestice čađe obično nastaju pri izgaranju dizelskog goriva. Čađa tako može predstavljati glavni problem motornih ulja u dizelovim motorima, što izaziva povećanje viskoznosti ulja. Što je više čađe u ulju, to će viskoznost više rasti. Iako je promjer čestica čađe reda veličine jedne desetine mikrometra, prekomjerna količina čađe u ulju, iznad približno 2-3 m/mt %, može izazvati čađom uzrokovano trošenje, uz samo povećanje viskoznosti. Još jedan problem što ga izaziva sadržaj čađe jest mogućnost začepljenja filtra za ulje. Stoga veliku ulogu motornog ulja predstavlja raspršivanje čestica čađe i sprječavanje njihova taloženja.

1.3 Oksidacijska stabilnost motornoga ulja

Oksidacija ulja uzrokovana je njegovim doticajem sa zrakom pod povišenom temperaturom [3] te se može dogoditi na bilo kojem vrućem dijelu motora. Oksidacija povezana s nitracijom motornoga ulja glavni je postupak opadanja kakvoće ulja u karteru poradi protjecanja vrućih plinova izgaranja. Oba ova postupka izazivaju zgušnjavanje ulja te su glavnim uzrokom nagomilavanja naslaga i lakova [4]. Na kraju vijeka trajanja ulja, oksidacija i nitracija odgovorne su za nagli rast viskoznosti [5].

1.4 Smična stabilnost

Modifikatori viskoznosti su polimerni spojevi koji se mogu pokazati nestabilnima zbog mehaničkoga stresa i povišene temperature. Ispitivanje smične stabilnosti, poput, primjerice, ispitivanja ASTM D 6278, uključeno je u brojne specifikacije radnih svojstava te je cilj onih koji se bave formulacijom ulja proizvesti smično stabilna ulja. Međutim, promjena viskoznosti može predstavljati problem, osobito ako je povezana s prekomjernom razrijeđenošću goriva.

2. Modifikatori viskoznosti za motorna ulja

Modifikatori viskoznosti za motorna ulja moraju udovoljiti proturječnim zahtjevima. Maksimalna se moć zgušnjavanja može postići modifikatorima visoke molekularne mase. S druge strane, za maksimalnu smičnu stabilnost motornoga ulja poželjni su modifikatori niske molekularne mase. Treći, pak, čimbenik što ga valja uzeti u obzir jest kako u formulacijama motornih ulja valja koristiti minimalnu razinu aditiviranosti maksimalne moći ugušćivanja, da bi se mogućnost nepravilnog rada motora svela na najmanju moguću mjeru.

Kemijski sastav i molekularna veličina najvažniji su elementi molekularne građe modifikatora viskoznosti. Svi danas dostupni modifikatori viskoznosti sastoje se od alifatskih ugljik-na-ugljik struktura. Srednja relativna molekularna masa modifikatora kreće se od približno 10000 do 1 milijuna. Glavne strukturalne razlike nalaze se u bočnim skupinama, koje se razlikuju i kemijski i prema veličini. Navedene varijacije kemijske strukture odgovorne su za različite odlike modifikatora viskoznosti, poput sposobnosti zgušnjavanja ulja, ovisnosti između viskoznosti i temperature, oksidacijske stabilnosti te štednje goriva [6].

Dostupne su različite vrste modifikatora viskoznosti, dok odabir ovisi o određenim okolnostima.

Poliizobutileni (PIB ili polibuteni), koji su se koristili još u Drugome svjetskome ratu, bili su glavni modifikatori viskoznosti krajem 50-ih. Oni obično ne osiguravaju zadovoljavajuća niskotemperaturna svojstva, kao niti radna svojstva dizelovih motora.

Polimetakrilati (PMA) sadrže alkilne bočne lance koji ometaju stvaranje kristala voska u ulju, osiguravajući tako odlična niskotemperaturna svojstva. Njihovi su nedostaci, međutim, razmjerno visoka cijena te sklonost stvaranju taloga u toplinski visokoopterećenim dizelovim motorima. Izrazito polarne vrste mogu se pojaviti i pretvoriti u gel u parafinskim uljima niske polarnosti (hidrokrekirana ulja i PAO). U suvremenim formulacijama motornih ulja uglavnom se koriste polimetakrilati, kao učinkoviti depresanti tecišta.

Olefinski se kopolimeri (OCP) uvelike koriste za motorna ulja radi svoje niske cijene i zadovoljavajućih radnih svojstava. Na tržištu se mogu naći razni OCP-i, razlikujući se uglavnom prema molekularnoj masi te omjeru etilena i propilena i, u tom smislu, sposobnosti zgušnjavanja, kao i prema drugim svojstvima, poput, primjerice, onih niskotemperaturnih.

Esteri stirenskih maleinskih anhidridnih kopolimera (stirenski esteri), višefunkcionalni su modifikatori viskoznosti. Kombinacija raznih alkilnih skupina uljima koja sadrže ove proizvode daje odlična niskotemperaturna svojstva. Stirenski esterni modifikatori viskoznosti korišteni su u motornim uljima namijenjenima štednji goriva te se još uvijek uvelike koriste u tekućinama za automatske mjenjače, a ujedno i kao depresanti tecišta.

Hidrogenirani stirenski-dienski (izopren ili butadien) kopolimeri (SBC) odlikuju se dobrim niskotemperaturnim svojstvima, kao i dobrim visokotemperaturnim svojstvima rada motora. Koriste se u malim količinama, napose u motornim uljima namijenjenima štednji goriva, dok pokazuju i određena protuoksidacijska svojstva. Njihova je slabost visoka cijena.

Hidrogenirani radijalni poliizopreni (STAR) pokazuju dobru smičnu stabilnost pri razmjerno niskim razinama aditiviranosti, u usporedbi s drugim vrstama modifikatora viskoznosti. Njihova su niskotemperaturna svojstva slična onima OCP modifikatora viskoznosti.

3. Ispitivanje smične stabilnosti

Trajni gubitak viskoznosti može biti izazvan djelomičnom mehaničkom depolimerizacijom ili toplinskom oksidacijom u prisutnosti kisika i dušika. Prema europskoj specifikaciji ACEA, smična stabilnost formuliranih ulja mjeri se kao postotak gubitka viskoznosti pri 100℃, mjereno nakon prolaska 30 ili 90 ciklusa u Bosch pumpi i sapnici pri sobnoj temperaturi od 20-25℃ i brzini vrtnje 925 min^{-1}. Motorna ulja koja udovoljavaju ACEA zahtjevima smične stabilnosti moraju ostati unutar svoje gradacije viskoznosti nakon prolaska 30 ili 90 ciklusa prema ispitivanju

ASTM D 6278. Molekularna veličina modifikatora viskoznosti važna je prije svega stoga što je veličina njihove molekule obrnuto proporcionalna njihovoj mehaničkoj stabilnosti. Uz isti učinak zgušnjavanja, PMA je manje stabilan od OCP modifikatora viskoznosti.

Privremeno se smicanje motornoga ulja može ocjenjivati dinamičkom viskoznošću pri visokim temperaturama i velikim brzinama smicanja (HTHSV), koja se obično mjeri simulacijskim viskozimetrom sa stožastim ležajem ili Ravenfieldovim viskozimetrom pri 150℃. U činkovitost pojedinih modifikatora viskoznosti iskazana kao prividna viskoznost opada redoslijedom PMA>OCP>SBC [7].

4. Smična stabilnost motornih ulja u radu

Uzeti su uzorci brojnih motornih ulja iz različitih vozila pri redovnoj izmjeni ulja te su sva ona potom analizirana utvrđivanjem uobičajenih dijagnostičkih parametara. Tablica 1 donosi podatke o viskoznosti nekih rabljenih motornih ulja uzetih iz benzinskih motora, koja nisu bila pod utjecajem niti prekomjerna sadržaja goriva niti/ili zamjetne oksidacijske degradacije.

Iz tablice 1 jasno proizlazi kako je smična stabilnost motornih ulja SAE xW-40 i SAE xW-30 posve različita. Dok je kinematička viskoznost motornih ulja SAE xW-40 za vrijeme rada u benzinskim motorima opadala, viskoznost motornoga ulja SAE xW-30 nije se niti promijenila, niti povećala, zbog toplinskom oksidacijom izazvane degradacije motornih ulja. Početna je viskoznost ulja SAE 5W-40 i SAE 10W-40 prikazana u tablici 1 kao približna vrijednost tipična za ulja navedene gradacije viskoznosti, dok se vrijednosti viskoznosti rabljenih ulja temelje na motornim uljima različitih proizvođača. Čini se kako postoje najmanje dvije vrste modifikatora viskoznosti korištenih u ispitanim formulacijama ulja, koje se razlikuju u smičnoj stabilnosti. Međutim, ključno je svojstvo modifikatora viskoznosti u formulacijama SAE xW-40 to što viskoznost ulja znatno opada za vrijeme rada motora: čak i do 30 %. Opadanje kinematičke viskoznosti gotovo je u svim slučajevima bilo tako dramatično da motorno ulje nije ostalo unutar izvornih gradacija viskoznosti, utvrđenih minimalnom vrijednošću viskoznosti od 12,5 mm^2s^{-1} pri 100 ℃.

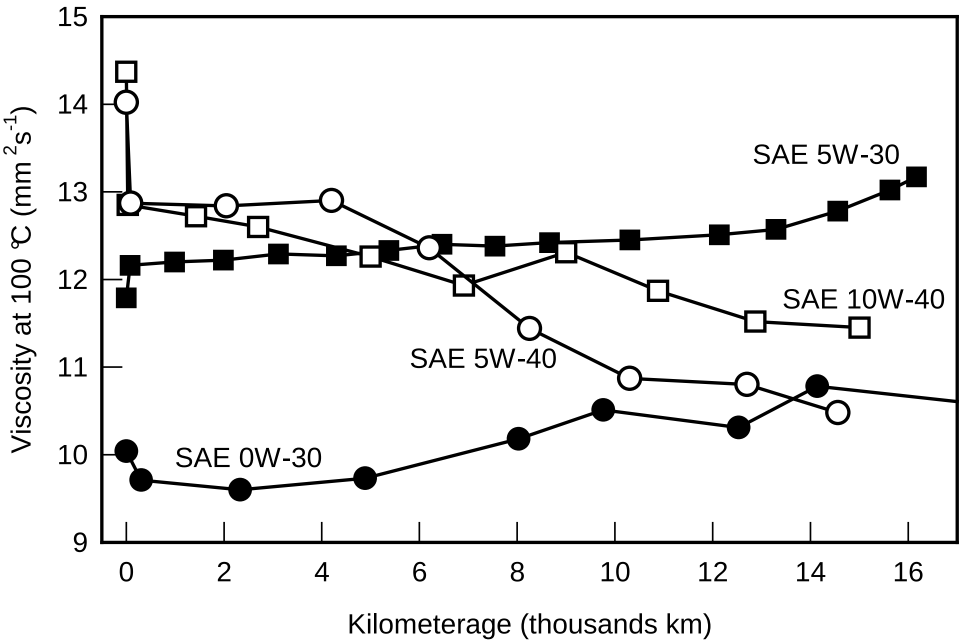
Kada se degradacija ulja uzrokovana toplinskom oksidacijom u konačnoj fazi radnoga vijeka motornoga ulja ubrza, viskoznost ulja počinje rasti. Taj postupak može motorna ulja SAE xW-40 vratiti u njihovu izvornu gradaciju viskoznosti, odnosno izazvati značajan porast viskoznosti kod motornih ulja SAE xW-30. Ova se potonja motorna ulja mogu formulirati korištenjem modifikatora viskoznosti s odličnom smičnom stabilnošću, ili pak znatno nižom količinom modifikatora viskoznosti u usporedbi s uljima SAE xW-40. Kao posljedica toga, kinematička viskoznost ulja SAE xW-30 nije se značajno mijenjala za vrijeme faze neposredno nakon izmjene ulja, no međutim, degradacija ulja uzrokovana toplinskom oksidacijom može izazvati značajan porast viskoznosti te se ulje u određenim slučajevima može prebaciti u sljedeću gradaciju viskoznosti, osobito kod ulja čija je HTHS viskoznost viša od 3,5 mPa.s (tablica 1).

Tablica 1: Podaci o viskoznosti za rabljena motorna ulja iz benzinskih motora

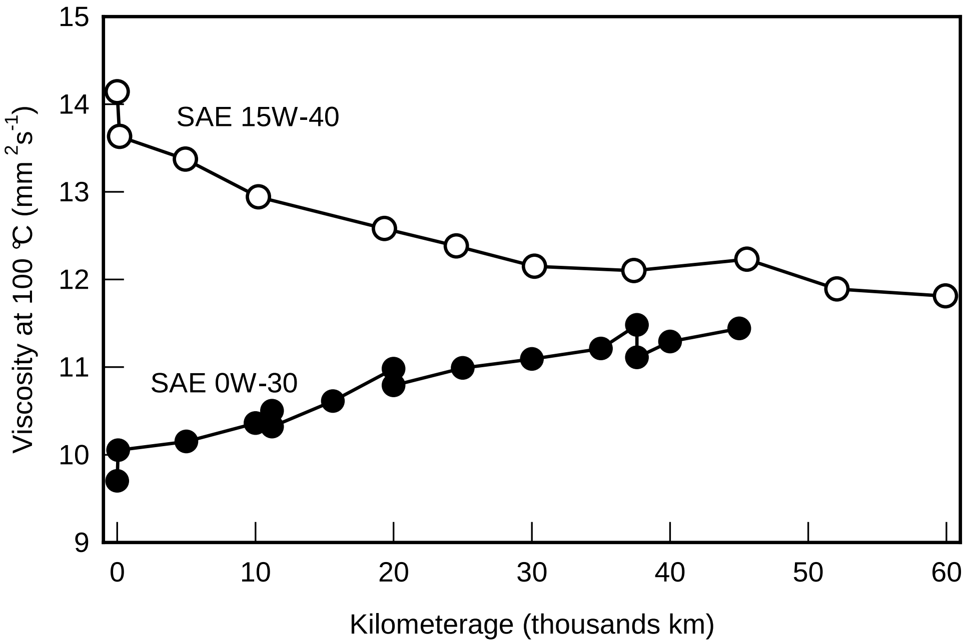
Motorno ulje	**Kilometri**	**Viskoznost (mm^2s^{-1})**		**Sadržaj goriva (m/m %)**
		40 °C	**100 °C**	
SAE 0W-40 novo		80,0	14,3	
ulje 1	15000	64,1	11,6	1,5
SAE 5W-40 novo		85	14	
ulje 2	3000	75,1	12,2	1,7
ulje 3	13000	74,7	12,3	1,6
ulje 4	13000	63,7	11,0	1,8
ulje 5	15000	61,3	10,5	1,1
ulje 6	18000	73,8	12,4	pokretan CNG-em
SAE 10W-40 novo		96	14	
ulje 7	15000	69,7	11,5	1,5
ulje 8	14000	81,0	12,8	1,6
ulje 9	7000	78,4	12,4	1,9
ulje 10	6000	68,1	11.2	1,2
SAE 5W-30 novo HTHS > 3.5 mPa.s		65,3	11,8	
ulje 11	16000	77,1	13,2	1,5
SAE 5W-30 novo HTHS < 3.5 mPa.s		53,1	9,4	
ulje 12	18000	60,1	10,2	1,6
SAE 0W-30 novo		54,7	9,9	
ulje 13	31000	58,2	10,4	0,8
ulje 14	29000	61,1	10,4	1,1
ulje 15	16000	69,1	11,6	1,0

Smična stabilnost i promjene viskoznosti motornih ulja vrlo su ilustrativne kada se vrijednosti kinematičke viskoznosti spoje s kilometražom. Ilustracije takve sprege prikazane su na slici 1 za benzinske motore te slici 2 za dizelove, no postoje i brojni drugi primjeri. Karakteristično je svojstvo motornih ulja SAE xW-40 to što je primijećena velika i brza promjena viskoznosti za vrijeme prvih stotinu prijeđenih kilometara. Početne su promjene viskoznosti ulja SAE xW-30 bile daleko manje izražene, izazvane miješanjem novoga dotočenoga ulja i ostatcima staroga. Daljnje promjene viskoznosti za vrijeme radnoga vijeka ulja vjerojatno su uzrokovane prometom, degradacijom ulja te njegovim nadolijevanjem.
Smična stabilnost motornih ulja u dizelovim motorima znatno je bolja negoli u benzinskima. Slika 2 prikazuje dva primjera: jedan iz dizelovoga motora putničkoga vozila VW 1.9 TDI, koji je radio po načelu dugog razmaka između izmjene ulja te iz autobusa VOLVO B10B s 10- litarskim dizelovim motorom. Početno je smicanje SAE 15W-40 bilo daleko manje negoli kod SAE xW-40 ulja u benzinskim motorima.

Daljnje je smanjenje viskoznosti uzrokovano postupnim smicanjem modifikatora viskoznosti. Sadržaj dizelskoga goriva u ulju bio je približno 1 m/m % na kraju radnoga vijeka ulja, tako da nije mogao značajno utjecati na viskoznost ulja. S druge pak strane, čađa može pridonijeti zgušnjavanju motornih ulja, no njezin je sadržaj bio značajan samo kod ulja SAE 0W-30 s približno 2,7 m/m % čađe na kraju radnoga vijeka ulja. Sadržaj čađe u ulju SAE 15W-40 za VOLVO autobus bio je vrlo nizak, oko 1,3 m/m %. Viskoznost SAE 5W-40 i/ili SAE 10W-40 motornih ulja izvađenih iz dizelovih motora putničkih vozila nakon izmjene po prijeđenih 15 tisuća km bila je obično blizu vrijednosti viskoznosti novoga ulja, pokazujući tek minimalne promjene viskoznosti, u usporedbi s viskoznostima prikazanima u tablici 1 za benzinske motore.



Slika 1: Promjena viskoznosti za vrijeme korištenja motornih ulja u benzinskim motorima



Slika 2: Promjena viskoznosti za vrijeme korištenja motornih ulja u dizelovim motorima

5. Stabilnost HTHS viskoznosti

Odabranim je motornim uljima nakon izmjene ispitana stabilnost HTHS viskoznosti. Dodatno su utvrđena također i niskotemperaturna svojstva tih ulja. Rezultati su prikazani u tablici 2. Sva su motorna ulja u tablici servisirana za maksimalni interval izmjene što ga preporuča OEM, većinom 15 tisuća km, a dugotrajna ulja SAE 0W-30 nakon 30 tisuća za benzinske motore, odnosno, nakon 38 za dizelove, te 40 ili 60 tisuća km za ulja SAE 15W-40 u dizelovim motorima predviđenima za velika opterećenja.

Vrijednosti HTHS viskoznosti iz tablice 2 pokazuju kako postoji isti trend kao i za kinematičku viskoznost. Motorna ulja SAE xW-40 većinom su pokazivala blago opadanje HTHS viskoznosti te je s druge strane primijećeno povećanje HTHS viskoznosti pri radu ulja SAE xW-30. Postoji ograničenje od 3,5 mPa.s za HTHS viskoznost, kako bi se razlikovala ACEA A5/B5 i obična ACEA A3/B3 i/ili A3/B4 motorna ulja. Valja primijetiti kako je većina motornih ulja za čitava njihova radnoga vijeka zadržana unutar intervala što ga propisuje ACEA. Jedino su dva motorna ulja gradacije SAE xW-40 nakon istjeka radnoga vijeka imala nešto nižu HTHS viskoznost od zahtijevane. Slična je situacija zabilježena i kod niskotemperaturnih svojstava izvađenih motornih ulja. Granica dinamičke viskoznosti ulja pri pokretanju motora što ju je postavila norma SAE J300 prekoračena je uglavnom kod ulja SAE xW-30, koja se za vrijeme rada u motorima zgušnjavaju.

Tablica 2: HTHS viskoznost i niskotemperaturna svojstva izvađenih motornih ulja

SAE	Motor	HTHS (mPa.s)		CCS (mPa.s)	
		novo ulje	rabljeno ulje	granica SAE J300	rabljeno ulje
0W-30	benzinski	3,0	3,4	6200/-35 ℃	6102
0W-30	dizelov	3,0	3,4	6200/-35 ℃	7258
5W-30	benzinski	3,6	3,9	6600/-30 ℃	9836
5W-40	benzinski	3,5	3,3	6600/-30 ℃	6735
10W-40	benzinski	3,6	3,6	7000/-25 ℃	5261
10W-40	benzinski	3,6	3,3	7000/-25 ℃	4794
15W-40	dizelov HD	4,0	3,5	7000/-20 ℃	6325
15W-40	dizelov HD	4,3	3,7	7000/-20 ℃	6853

6. Zaključak

Praćen je rad motornih ulja različitih gradacija viskoznosti, kako bi se utvrdile promjene viskoznosti i smična stabilnost. Procjena je podataka o kinematičkoj viskoznosti pokazala kako su motorna ulja SAE xW-40 sklona značajnu opadanju kinematičke viskoznosti za vrijeme rada. Smična stabilnost motornih ulja SAE xW-30 pokazala se daleko boljom te se ispostavilo kako se ona zgušnjavaju poradi utjecaja radnih uvjeta, poput degradacije zbog toplinske oksidacije i/ili sadržaja čađe. Taj je učinak zamjetljiviji u benzinskim, negoli u dizelovkim motorima. Što se, pak, tiče kinematičke viskoznosti, sličan je učinak utvrđen i za druga svojstva viskoznosti motornih ulja, poput HTHS viskoznosti i dinamičke viskoznosti ulja pri pokretanju motora.

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SHEAR STABILITY OF MOTOR OILS

Abstract

Paper summarizes influences on motor oil viscosity, such as shear stability of viscosity modifiers, fuel and/or soot content, and thermal oxidation degradation of oils. Significance of individual aspects was monitored for several motor oils of different viscosity grades during over-the-road service of vehicles powered by spark ignition as well as diesel engines. Trends of viscosity changes were noticed and evaluated.

1. Viscosity of motor oils in service

Viscosity is one of the basic functional properties of motor oils. It is measured as a resistance of the oil to flow while forced through a capillary [1]. Viscosity of motor oils is set up during their production by a blending of suitable base oils and by addition of viscosity modifiers. Role of the viscosity modifier is to thicken the base oil and to increase its viscosity index so as to meet the desired viscosity class. In an optimal way, viscosity properties should be stable throughout the oil lifetime. However, many effects can influence on the oil viscosity during the oil service.

1.1 Fuel

Petrol or diesel fuel is present in a small amount in almost each motor oils in service. High fuel dilution can cause alarming decrease of the oil viscosity and, in an extreme case, the HTHS viscosity can decrease under the acceptable value. According to Skoda-Auto (member of the WV Group), maximum of the fuel dilution cannot exceed 4 % for petrol engines. Source of an excessive fuel dilution is mostly due to an unsuitable fuel used and/or a failure of the injection system [2]. In some cases, frequent cold starting can also considerably contribute to the fuel dilution, especially to the increased amount of light petrol compounds, which otherwise evaporate under operational temperature.

1.2 Soot

Soot particulates are usually formed when a diesel fuel is combusted. Soot thus can be the main problem of motor oils in diesel engines leading to increased oil viscosity. The more soot in oil the higher viscosity increase. Although diameter of the soot particulates is in the order of one tenth of micrometer, excessive amount of soot in oil, above about 2-3 wt %, can effect in soot induced wear in addition to the viscosity increase. Another problem arising from the soot content can be a possibility of oil filter clogging. It is thus the great role of motor oil to keep soot particles bulk dispersed and not to allow them to settle.

1.3 Oxidation stability of motor oil

Oil oxidation is caused by a contact of oil with air under elevated temperature [3] and it can proceed on any hot site of the engine. Oxidation associated with nitration of the motor oil is the main oil deterioration process in crankcase due to blow-by of hot combustion gases. Both processes lead to oil thickening and are the major cause of the build-up of varnish and lacquer [4]. At the end of the oil lifetime, oxidation and nitration are responsible for sudden viscosity increase [5].

1.4 Shear stability

Viscosity modifiers are polymeric compounds that can be unstable under mechanical stress and elevated temperature. Shear stability test, such as ASTM D 6278, is incorporated in many performance specifications and it is goal of the oil formulators to produce shear stable oils. However, viscosity shear down can represent a problem especially when associated with excessive fuel dilution.

2. Viscosity modifiers for motor oils

In viscosity modifiers design for engine oils there are conflicting requirements to make up. Maximum of the thickening power can be accomplished by high molecular weight modifiers. On the other hand, for a maximum shear stability of the motor oil the low molecular weight modifiers are desirable. And third factor to consider is that a minimum treat rate with maximum of the thickening power should be used in motor oil formulations to minimize the possibility of engine fouling.

Chemical structure and molecular size are the most important elements of the molecular architecture of viscosity modifiers. Viscosity modifiers available today all consist of aliphatic carbon-to-carbon backbones. The mean relative molecular weight of modifiers ranges from about 10 000 to 1 million. The major structural differences lie in the side groups, which differ both chemically and in size. These variations in chemical structure are responsible for various properties of viscosity modifiers such as oil thickening ability, viscosity-temperature dependency, oxidation stability and fuel economy characteristics [6].

Many types of viscosity modifiers are available, and choice depends on the particular circumstances.

Polyisobutylenes (PIB or Polybutenes) used as early as World War II, were the predominant viscosity modifiers at the end of the 1950s. They generally do not provide satisfactory low-temperature and diesel performance.

Polymethacrylates (PMA) contain alkyl side chains that interfere with the formation of wax crystals in the oil, thereby providing excellent low-temperature properties. Their demerit is in relative high cost and tendency to form deposits in thermally loaded diesel engines. Highly polar types may precipitate and gelify in alkanic oils with low polarity (hydrocracked oils and PAO). In modern motor oil formulation polymethacrylates are predominantly used as efficient pour point depressants.

Olefin Copolymers (OCP) are widely used for motor oils due to their low cost and satisfactory engine performance. Various OCPs are on the market differing mainly in molecular weight and the ratio of ethylene to propylene and thus in thickening efficiency and other, such as low temperature, properties.

Esters of Styrene Maleic Anhydride Copolymers (Styrene Esters) are multifunctional viscosity modifiers. A combination of various alkyl groups imparts excellent low-temperature properties to oils containing these products. Styrene ester viscosity modifiers have been used in fuel economy motor oils and are still used extensively in automatic transmission fluids and as pour point depressants.

Hydrogenated Styrene-Diene (isoprene or butadiene) Copolymers (SBC) are characterized by good low-temperature properties and good high-temperature engine performance. They are used at low treat rate especially in fuel economy engine oils, and they also exhibit some antioxidant properties. Their weakness is higher cost.

Hydrogenated Radial Polyisoprenes (STAR) demonstrate good shear stability at relatively low treatment rates compared to other viscosity modifier types. Their low-temperature properties are similar to those of the OCP viscosity modifiers.

3. Shear stability testing

Permanent viscosity loss can be caused by partial mechanical depolymerisation or by thermo-oxidation in the presence of oxygen and nitrogen. According to the European ACEA specification the shear stability of formulated oils is measured as the percent viscosity loss at 100℃ measured after passing 30 or 90 cycles in Bosch pump and injector nozzle at room temperature 20-25°C and 925 rpm. Motor oils that meet the ACEA shear stability requirements have to stay in the viscosity grade after passing 30 or 90 cycles according to the ASTM D 6278 test. Molecular size of viscosity modifiers is primarily important as the larger their molecule, the lower is their mechanical stability. With the same thickening effect, the PMA is less stable than OCP viscosity modifiers.

Temporary motor oil shear can be measured in terms of the high temperature high shear viscosity (HTHSV) which is usually measured by Tapered Bearing Simulator Viscometer or by Ravenfield Tapered Plug Viscometer at 150℃. Efficiency of individual viscosity modifiers expressed as apparent viscosity decreases is in the order PMA>OCP>SBC [7].

4. Shear stability of motor oils in service

A number of used motor oils were taken from different cars at the regular oil drain and all motor oils were then analysed by determining usual diagnostic parameters. Table 1 brings viscosity data of some used motor oils taken from petrol powered engines that were not influenced by excessive fuel content and/or by extensive oxidative degradation.

It is clearly evident from the Table 1 that shear stability of SAE xW-40 and SAE xW-30 motor oils was quite different. Whereas kinematic viscosity of the SAE xW-40 motor oils decreased during service in petrol engines, viscosity of SAE xW-30 motor oil did not change or increased due to thermal oxidation degradation of motor oils. Initial viscosity of the SAE 5W-40 and SAE 10W-40 oils is given in the Table 1 as an approximate value typical for these viscosity grade oils, and viscosity values of used oils were based on motor oils from different producers. It seems that there were at least two types of viscosity modifiers commonly used in oil formulations examined differing in shear stability. However, the key property of the viscosity modifiers in SAE xW-40 formulations is that oil viscosity significantly decreases during service making the viscosity drop as high as 30%. Kinematic viscosity decrease was almost in all cases so dramatic that the motor oil did not stay in the original viscosity grades determined by the minimum viscosity value of 12.5 mm^2s^{-1} at 100 ℃.

When thermal oxidation degradation of oil accelerates in the final stage of the motor oil lifetime then viscosity of the oil starts to increase. That process can get the SAE xW-40 motor oils back to their original viscosity grade or it can cause remarkable viscosity increase for the SAE xW-30 motor oils. The latter motor oils can be formulated by using viscosity modifiers with excellent shear stability or substantially lower amount of common viscosity modifiers can be used in comparison to the SAE xW-40 oils.

Table 1: Viscosity data of used motor oils from petrol powered engines

Motor oil	**Kilometres**	**Viscosity (mm^2s^{-1})**		**Fuel Content (wt %)**
		40 ℃	**100 ℃**	
SAE 0W-40 new		80,0	14,3	
oil 1	15000	64.1	11.6	1,5
SAE 5W-40 new		85	14	
oil 2	3000	75.1	12.2	1.7
oil 3	13000	74.7	12.3	1.6
oil 4	13000	63.7	11.0	1.8
oil 5	15000	61.3	10.5	1.1
oil 6	18000	73.8	12.4	CNG powered
SAE 10W-40 new		96	14	
oil 7	15000	69.7	11.5	1.5
oil 8	14000	81.0	12.8	1.6
oil 9	7000	78.4	12.4	1.9
oil 10	6000	68.1	11.2	1.2
SAE 5W-30 new HTHS > 3.5 mPa.s		65.3	11.8	
oil 11	16000	77.1	13.2	1.5
SAE 5W-30 new HTHS < 3.5 mPa.s		53.1	9.4	
oil 12	18000	60.1	10.2	1.6
SAE 0W-30 new		54.7	9.9	
oil 13	31000	58.2	10.4	0.8
oil 14	29000	61.1	10.4	1.1
oil 15	16000	69.1	11.6	1.0

As a result, kinematic viscosity of the SAE xW-30 oils did not significantly change during the early stages of the oil drain interval, however, thermal oxidation degradation of the oils can cause substantial viscosity increase and the oil can in some instances be shifted to the next viscosity grade, especially for the oils with HTHS viscosity higher than 3.5 mPa.s (Table 1).

Shear stability and viscosity changes of motor oils are very illustrative when kinematic viscosity values are plotted against kilometerage. Illustrations of such a plot are shown in Figure 1 for petrol engines and in Figure 2 for diesel engines, however many other examples are available. Characteristic feature of the SAE xW-40 motor oils was that the major and rapid viscosity change was observed during the initial one hundred kilometers of oil service. Initial viscosity changes of SAE xW-30 oils were much less pronounced and were caused by mixing new oil filled and remnants of old motor oil. Further viscosity changes during the oil life were probably caused by a character of the traffic, by oil degradation, and by oil topupping.

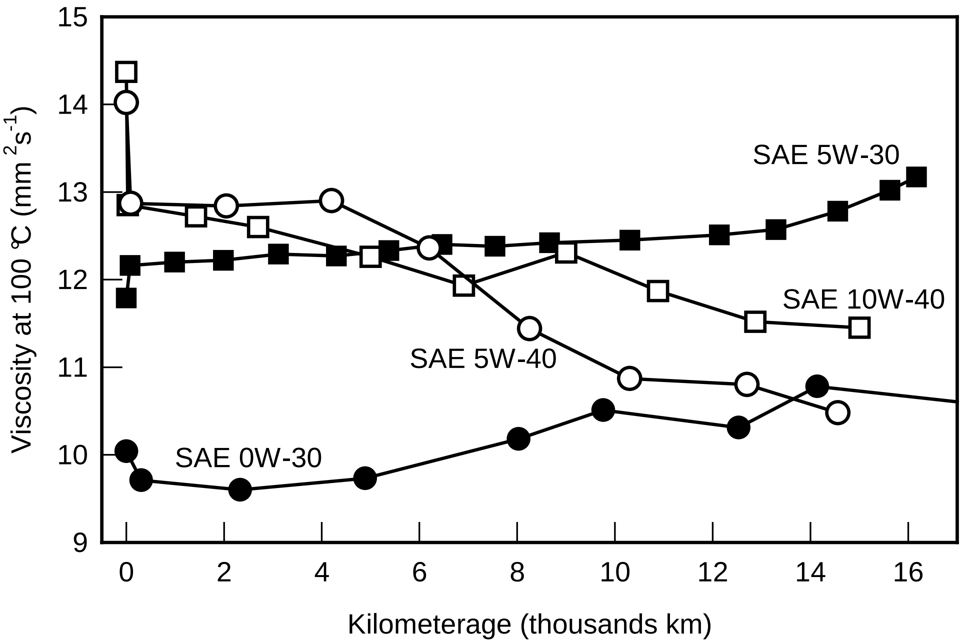

Figure 1: Viscosity shear down during service of motor oils in petrol engines

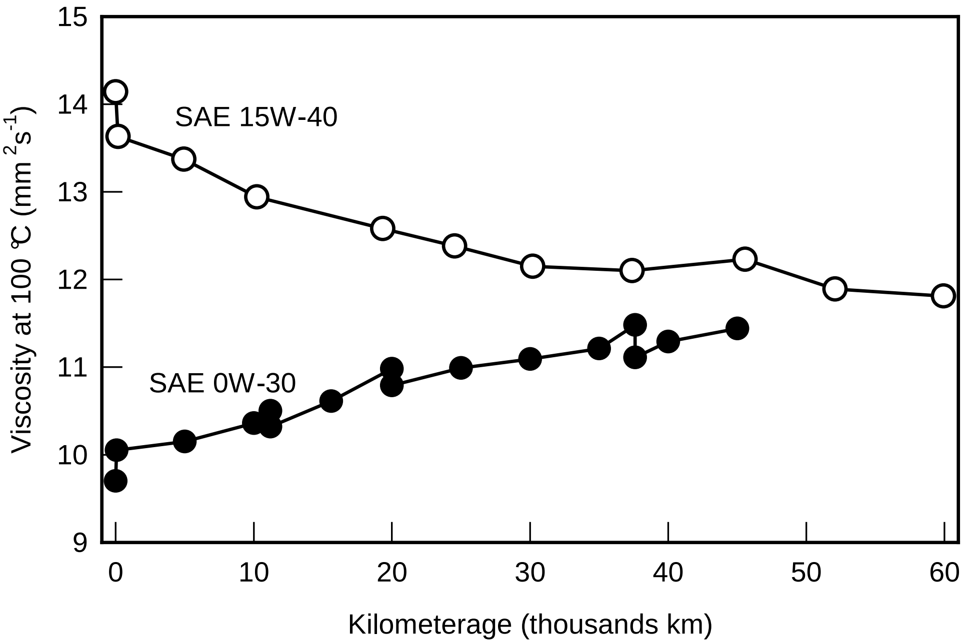

Figure 2: Viscosity shear down during service of motor oils in diesel engines

Shear stability of motor oils in diesel engines is much better than in petrol engines. Figure 2 shows two examples, one from a diesel engine of passenger car VW 1.9 TDI, which operated in the long drain interval regime, and the other from a bus VOLVO B10B with 10 liter diesel engine. Initial shear down of the SAE 15W-40 was much less than for the SAE xW-40 oils in petrol engines. Further viscosity decrease came from gradual shearing down of viscosity modifiers. Diesel fuel content in the oil was about 1 wt % at the end of the oil life and so it cannot influence in a substantial way on the oil viscosity. On the other hand, soot can contribute to thickening of motor oils, however, the soot content was only significant for the SAE 0W-30 oil with about 2.7 wt % of soot at the end of the oil life. Soot content in the SAE 15W-40 oil of the VOLVO bus was very low, about 1.3 wt %. Viscosity of SAE 5W-40 and/or SAE 10W-40 motor oils drained from diesel engines of passenger cars after 15 thousands km interval was usually near the viscosity value of the new oil showing only minor viscosity changes in comparison to viscosities shown in Table 1 for spark ignition engines.

5. Stability of HTHS viscosity

Selected motor oils were after the oil drain tested for stability of the HTHS viscosity. Additionally low temperature properties of the oils were also determined. Results are shown in Table 2. All motor oils in the Table were serviced for the maximum drain interval recommended by OEM, i.e. mostly 15 thousands km, longlife oils SAE 0W-30 for 30 thousands for petrol engine and 38 thousands km for diesel engine, and 40 or 60 thousands km for SAE 15W-40 oils in heavy duty diesel engine.

Table 2: HTHS viscosity and low temperature properties of motor oils drained

SAE	Engine	HTHS (mPa.s)		CCS (mPa.s)	
		new oil	used oil	limit SAE J300	used oil
0W-30	petrol	3.0	3.4	6200/-35 °C	6102
0W-30	diesel	3.0	3.4	6200/-35 °C	7258
5W-30	petrol	3.6	3.9	6600/-30 °C	9836
5W-40	petrol	3.5	3.3	6600/-30 °C	6735
10W-40	petrol	3.6	3.6	7000/-25 °C	5261
10W-40	petrol	3.6	3.3	7000/-25 °C	4794
15W-40	diesel HD	4.0	3.5	7000/-20 °C	6325
15W-40	diesel HD	4.3	3.7	7000/-20 °C	6853

HTHS viscosity values in Table 2 show that there is the same trend as for the kinematic viscosity. SAE xW-40 motor oils mostly exhibited slight decrease of the HTHS viscosity and, on the other hand, increase of HTHS viscosity due to oil service for the SAE xW-30 oils was observed. There is a limit of 3.5 mPa.s for the HTHS viscosity to distinguish between ACEA A5/B5 and common ACEA A3/B3 and/or A3/B4 motor oils. It is worth to note that most motor oils were kept for all their life inside the interval prescribed by ACEA. There were only two motor oils of the SAE xW-40 grade that had after service life slightly lower HTHS viscosity than required. Similar situation was also found for the low temperature properties of motor oils drained. When cranking viscosity limit given by the SAE J300 standard was exceeded it was mostly the case of the SAE xW-30 oils that thicken during their service in engines.

6. Conclusion

Motor oils of several viscosity grades were monitored in their service life for viscosity changes and shear stability. Evaluation of kinematic viscosity data showed that SAE xW-40 motor oils are susceptible to a significant decrease of their kinematic viscosity during their service. Shear stability of SAE xW-30 motor oils was found much better and the oils rather tended to thicken due to a service impact such as thermal oxidation degradation and/or soot content. The effect was more pronounced in petrol powered engines than in diesel engines. As for the kinematic viscosity, similar effect was also found for other viscosity characteristics of motor oils such as HTHS viscosity and cranking viscosity.

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	ključne riječi	key words
621.892.097.2	motorno ulje za automobile	automotive motor oil
621.436	dizelov motor	diesel engine
621.434	benzinski motor	gasoline engine
532.133.091	smična stabilnost	shear stability
665.765.035	primjenska svojstva mazivog ulja	lubricating oil application properties

Autori / Authors:
Jaroslav Cerny
Odjel naftne tehnologije i petrokemije, Zavod za kemijsku tehnologiju, Technicka 5, 16628 Prag, Češka Republika

Ivana Vaclavickova
Paramo a.s., Prerovska 560, 53006 Pardubice, Češka Republika

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