Danka Šikuljak, Omer Kovač, Novak Damjanović

ISSN 0350-350X
GOMABN 55, 1, 23-32
Professional paper

THE INFLUENCE OF BASE OILS AND VISCOSITY IMPROVER ON LOW TEMPERATURE PROPERTIES OF GEAR OILS

Abstract

The main function of gear oils in motor vehicles (transmission and differential) is to transfer power from the engine to the axle and wheels. During operation, gears tooth surfaces in these elements are exposed to extremely high pressures and impact loads. In order to ensure proper operation and adequate lubrication of all elements, oils used in these machine elements must provide following properties: good viscosity properties (in order to provide sufficient oil film thickness at elevated temperatures), protection against wearing and damaging at conditions of extreme pressures and loads, as well as excellent low-temperature properties for easier shifting in cold weather.

Besides the above mentioned properties, modern gear oils must also have nothing less important properties as: high thermal-oxidation stability, extended oil drain interval, low foaming tendency, corrosion protection, high shear stability, etc. Meeting the above requirements is achieved by using of high quality base oils (groups II, III, IV and V) and selected additive package. Unlike conventional base oils, these oils have significantly better low-temperature properties and therefore by applying of such oils improved efficiency is achieved.

This paper presents results obtained in researching the influence of base oils and two polymer types on properties of gear oils, by focusing on its low-temperature properties. In the gear oils formulations were used group III, group IV and group V base oils. For the evaluation of low-temperature properties were used results for dynamic viscosity measurments perfomed by Brookfield viscometer - test method ASTM D 2983 (under low shear rate) and Cold Cranking Simulator - test method ASTM D 5293 (under high shear rate).

Key words: *gear oils, lubrication, low-temperature properties, base oils, additives*

1. Introduction

Ensuring proper and good lubrication of gears in gear assemblies is one of the main factors that ensure normal operation and reliability in operation. Gear oil must provide good viscosity-temperature properties, excellent protection under extreme pressures and high loads, corrosion protection, as well as excellent low-temperature properties, which must ensure the smooth lubrication in conditions of extremely low temperatures. These requirements can meet only lubricant formulated with high quality base oils and additive package which provides multifunctional properties. In these formulations are used mineral base oils, hydrocracked base oils or synthetic hydrocarbons. Lubricant additives in these formulations are: corrosion inhibitors, anti-wear and EP additives, pour point depressants, oxidation inhibitors, friction modifiers. Low temperature properties of gear oils are formally defined by the SAE J 306 standard, which provides the maximum temperature for a viscosity of 150,000 mPa s measured on a Brookfield viscometer [1-6]. The aim of this work is evaluation of the influence of base oil type and viscosity modifier on the low temperature properties of gear oils.

2. Experimental part

The paper investigates the impact of type of base oils on low temperature properties of gear oils. The samples of SAE 75W-90 gear oils were prepared from different base oils, two viscosity modifiers and GL 4/5 additive package.

2.1. Materials

2.1.1. Base oils

In gear oil formulations were used API group III, group IV and group V base oils. The main physical-chemical properties are given in Table 1.

2.1.2. Additive package

In tested gear oil formulations multifunctional additive package in a dosage of 10% were used. This additive package is used in TDL (Total Drive Line) gear oils suited for the lubrication of all drive elements, from synchronized and nonsynchronyzed manual transmission to hypoid geared axle drives and differentials. At this dosage it meets the following specifications: API GL-4/GL-5; API MT-1; MIL-PRF-2105E; ARVIN MERITOR 0-76-N; DAF; IVECO; MAN 341 Type Z-2; MAN 341 Type E-3; MAN 342 Type M-3; MB-235.8; ZF TE-ML 02B/05B/07A/12B/16F/17B/19C/21B; SCANIA STO 1:0.

Due to its composition based on olefin sulfides, phosphoric acid esters and aryl thiophosphates [7] this additive in a lubricant formulation provides outstanding antiwear and EP protection. In the Table 2 are shown some physical and chemical properties of the additive package.

2.1.3. Viscosity modifiers

As viscosity modifiers in these formulations were used two polymethacrylate (PAMA) polymers of European’s leading improver manufacturers (Table 3) [7].

Table 1: Physical-chemical properties of base oils used in gear oils formulations

Property	Method	Unit	HC-SDW	HC-CDW	PAO 4	PAO 6/1	PAO 150	PAO 65	PAO 6/2	AN
Viscosity at 40 °C	BAS ISO 3104	mm²/s	21.03	19.99	17.66	30.85	1650	585.7	29.93	31.20
Viscosity at 100 °C	BAS ISO 3104	mm²/s	4.39	4.28	3.95	5.76	158.1	64.03	5.84	5.09
Index viscosity	BAS ISO 2909	-	119	122	121	131	211	182	142	85
Density at 15 °C	ASTM D 5002	kg/m³	847.7	835.5	818.3	826.2	846.5	843.3	826.7	908.9
Flash point, °C	ISO 2592	°C	230	227	228	240	290	276	252	226
Pour point, °C	BAS ISO 3016	°C	-12	-21	<-60	<-60	-33	-33	-56	-36
API GROUP			III	III	IV	IV	IV	IV	IV	V
TYPE OF BASE OIL			HC* base oil	HC* base oil	PAO	PAO	mPAO	mPAO	PAO	AN**
TYPE OF DEWAXING PROCESS			Solvent	Catalytic	-	-	-	-	-	-

* Hydrocracked, ** Alkylated naphthalene

Table 2: Physical and chemical properties of additive package

Characteristics	Value	Chemical composition	Value
Viscosity at 10 °C, mm²/s	8.8	Sulphur, w/w%	20.6
Pour point, °C	-33	Boron, w/w%	0.52
Flash point, °C	78	Magnesium, w/w%	0.95
Density at 15 °C, kg/m³	1010	Nitrogen, w/w%	0.61
		Phosphorus, w/w%	1,63

2.1.4. Gear oil formulations

From above mentioned components eleven samples of SAE 75W-90 gear oils were prepared. Formulations are given in Tables 4, 5 and 6.

Table 3. Typical properties of used viscosity modifiers

	Viscosity modifier A	Viscosity modifier B
Application	A shear stable VI improver for multigrade gear lubricants	
Type	Viscous concentrate of poly(alkyl methacrylate) (PAMA) in a solvent-refined carrier oil	
Viscosity at 100 °C, mm²/s	450	133
Density at 15 °C, kg/m³	0.93	0.98
Shear stability index, KRL, 20 h	under 20	under 20

Table 4: Lubricant formulations with viscosity modifier A

SAE 75W-90					
FORMULATION	I	II	III	IV	V
HC-SDW, w/w %	61	-	30.5	-	-
HC-CDW, w/w %	-	61	30.5	-	-
PAO 4, w/w %	-	-	-	60	-
PAO 6/1, w/w %	-	-	-	-	64
VISCOSITY MODIFIER A, w/w %	29	29	29	30	26
ADDITIVE PACKAGE, w/w%	10	10	10	10	10

Table 5. Lubricant formulations with viscosity modifier B

SAE 75W-90				
FORMULATION	I	II	III	IV
HC-CDW, w/w %	54	-	26.5	-
PAO 4, w/w %		52	26.5	-
PAO 6/1, w/w %	-	-	-	59
VISCOSITY MODIFIER B, w/w %	36	38	37	31
ADDITIVE PACKAGE, w/w%	10	10	10	10

Table 6. Lubricant formulations without viscosity modifiers

SAE 75W-90		
FORMULATION	I	II
PAO 6/2, w/w %	40.4	26
PAO 150, w/w %	31.1	-
PAO 65, w/w %	-	45
AN , w/w %	18,5	19
ADDITIVE PACKAGE, w/w %	10	10

2.2. Methods

The evaluation of low-temperature properties of tested samples was performed by determination of dynamic viscosity by Brookfield viscometer (Figure 1) according to the method ASTM D 2983 on different temperatures and low shear rate.

In addition, viscosity was measured by Cold Cranking Simulator (Figure 2) on low temperatures and high shear rate according to method ASTM D 5293.

Besides the above mentioned, some basic physical and chemical properties were measured according to the test methods specified in Table 7 [8].

Table 7: Test methods

Characteristic	Test Method	Unit
Viscosity at 40 °C	*BAS **ISO 3104	mm²/s
Viscosity at 100 °C	BAS ISO 3104	mm²/s
Viscosity index	BAS ISO 2909	-
Density at 15 °C	***ASTM D 5002	kg/m³
Pour point	BAS ISO 3016	°C
Dynamic viscosity measured by Brookfield viscometer	ASTM D 2983	mPa s
Dynamic viscosity measured by Cold Cranking Simulator	ASTM D 5293	mPa s

**The Institute for Standardization of Bosnia and Herzegovina*
***International Organization for Standardization*
****American Society for Testing Materials*

Figure1: Brookfield viscometer

Figure 2: Cold Cranking Simulator

3. Results and discussion

Test results with viscosity improver A

In Table 8 and Figures 3 and 4 the test results of samples formulated with shear stable polymethacrylate viscosity modifier (modifier A) which is used in gear oil formulations (Table 4) are shown.

Table 8. Physical-chemical properties of gear oils with viscosity modifier A

Property	Unit	Formulation I	Formulation II	Formulation III	Formulation IV	Formulation V
Viscosity at 40 °C	mm^2/s	98.9	89.93	92.77	85.94	102.04
Viscosity at 100 °C	mm^2/s	16.25	15.85	16.14	15.71	16.9
Viscosity index	-	178	189	187	194	181
Density at 15 °C	kg/m^3	880.5	877.4	881.3	867.7	869.3
Dynamic viscosity measured by Brookfield viscometer at -40 °C	mPas	205456	55688	65586	27494	47190
Dynamic viscosity measured by CCS -25 °C -20 °C	mPas	7000 4150	5400 3050	6200 3600	4100 2450	6100 4100

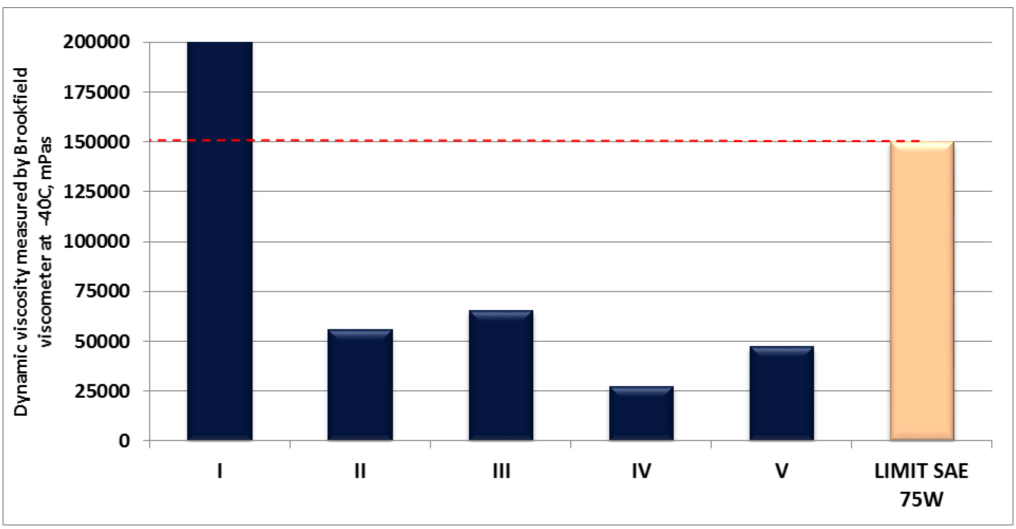

Figure 3: Influence of base oil type on dynamic viscosity measured by Brookfield viscometer of gear oils formulated with improver A

As shown in Figure 3 lubricant formulations with viscosity modifier A have dynamic viscosity (measured by Brookfield viscometer) significantly below the allowed limit of 150000 mPas. Only the formulation with HC-CDW (hydrocracked-dewaxing) oil has viscosity above this limit. Also, based on these results it can be concluded that lubricants formulated with polyalphaolefins (PAO) have much better low temperature properties than the formulation with group III base oils. Dynamic viscosity measured by CCS has shown that all tested samples satisfy the requirements of SAE 10W-XX. Results showed that samples with PAO have better low temperature properties, compared with samples formulated with group III base oils.

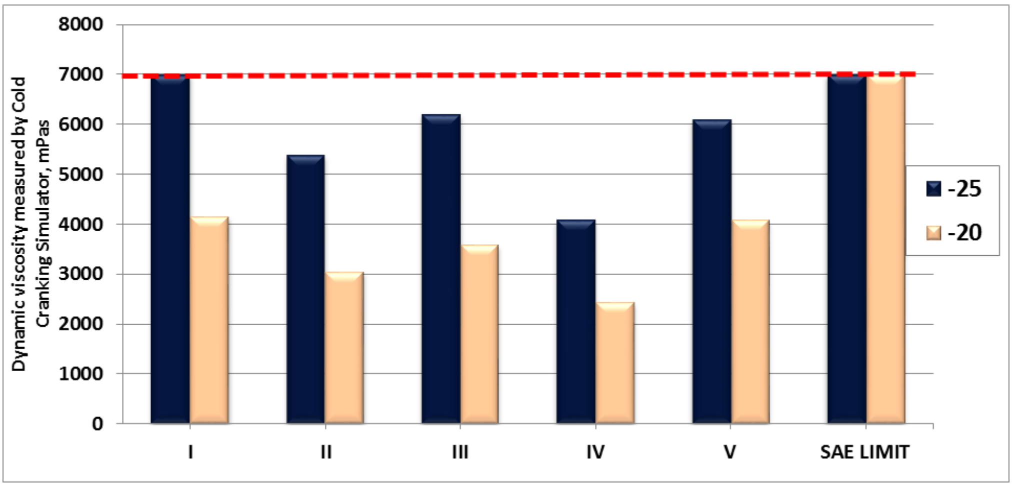

Figure 4: Influence of base oil type on dynamic viscosity measured by Cold Cranking Simulator of gear oils formulated with improver B

Test results of formulation with viscosity improver B

The formulations of gear oil prepared with polymethacrylate viscosity index improver of the second manufacturer are given in Table 5. The obtained results are shown in Table 9 and Figures 5 and 6.

The results showed that low-temperature properties of gear oils formulated with viscosity modifier B are much worse than those with viscosity modifier A. Furthermore, only the gear oils formulated with PAO have fulfilled the requirements of SAE 75W.

Dynamic viscosity of tested samples measured by Cold Cranking Simulator was under the limit for SAE 15W-XX. The best results showed samples formulated with polyalphaolefins.

Table 9: Physical-chemical properties of gear oils with viscosity modifier B

Property	Unit	Formulation I	Formulation II	Formulation III	Formulation IV
Viscosity at 40 °C	mm^2/s	102.55	101.2	101.32	106.85
Viscosity at 100 °C	mm^2/s	14.83	15.03	14.92	15.27
Viscosity index	-	150	156	153	5.74
Density at 15 °C	kg/m^3	874.8	866.8	871.1	866.0
Dynamic viscosity measured by Brookfield viscometer at -40 °C	mPas	600000	77583	185160	73584
Dynamic viscosity measured by CCS -25 °C -20 °C	mPas	9800 6700	7500 5200	9600 6200	8150 5750

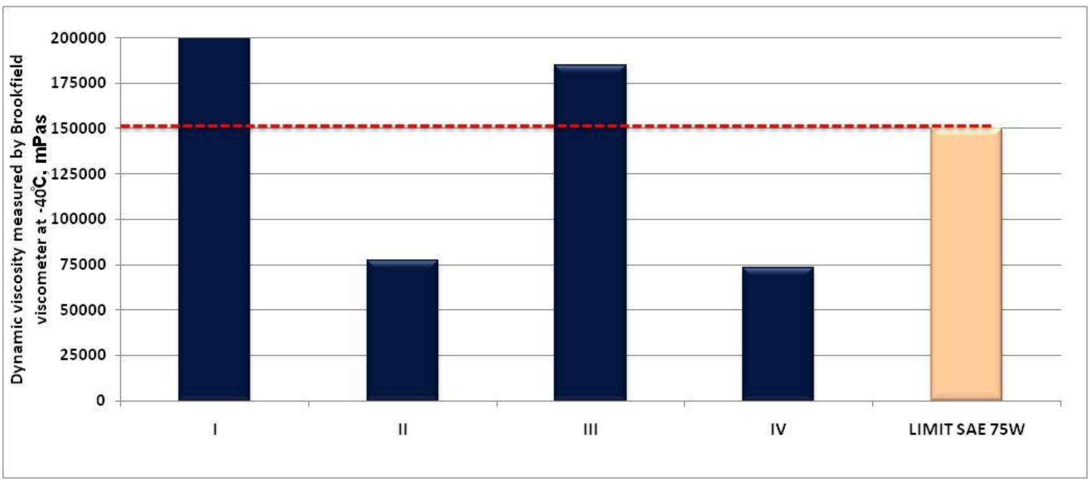

Figure 5: Influence of base oil type on dynamic viscosity measured by Brookfield viscometer of gear oils formulated with improver B

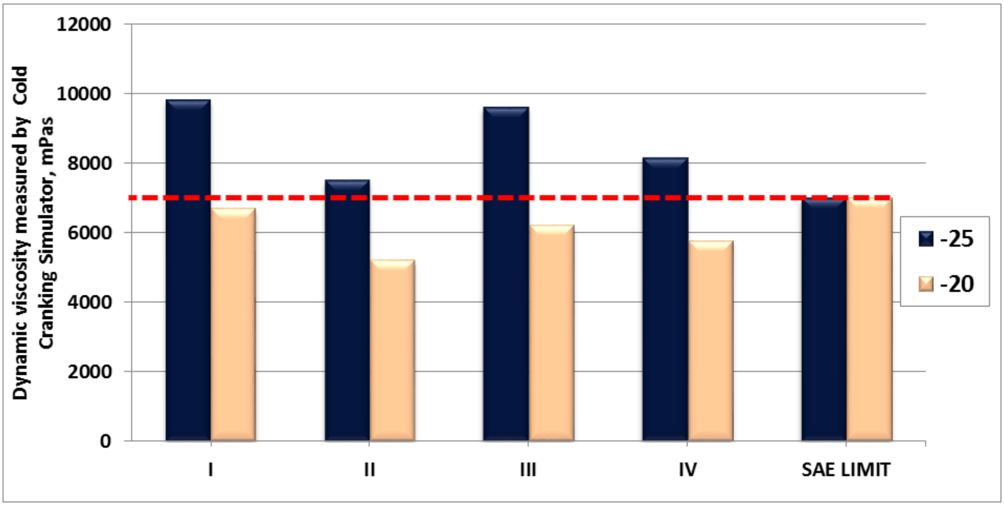

Figure 6: Influence of base oil type on dynamic viscosity measured by Cold Cranking Simulator of gear oils formulated with improver B

Test results of formulations without viscosity improver

In the third series of tests, viscosity modifier was not used but the samples were formulated from high molecular polyalphaolefins and alkylated naphthalene, as it is shown in Table 6. Dynamic viscosity of both samples was much lower than the limit of 150000 mPas. Results for viscosity measurements performed by Cold Cranking Simulator have shown that tested samples satisfy the requirements of SAE 15W-XX viscosity grade.

Table 10: Physical and chemical properties of gear oils formulated without viscosity modifier

Property	Method	Unit	Formulation I	Formulation II
Viscosity at 40 °C, mm^2/s	BAS ISO 3104	mm^2/s	95.06	101.73
Viscosity at 100 °C, mm^2/s	BAS ISO 3104	mm^2/s	14.84	15.27
Viscosity index	BAS ISO 2909	-	163	158
Density at 15 °C, kg/m^3	ASTM D 2983	kg/m^3	859.8	863.6
Dynamic viscosity measured by Brookfield viscometer at -40 °C	ASTM D 5293	mPas	40 991	67 386
Dynamic viscosity measured by CCS, -20 °C	ASTM D 5002	mPas	3900	4900

4. Conclusion

- Performed tests have shown that type of base oil has a significant influence on the low temperature properties of gear oils.
- With proper choice of viscosity modifiers, group III base oils produced by hydroisomerization process and polyalphaolefins can be used for the manufacture of gear oil SAE 75W-XX.
- Gear oils formulated with PAO showed much better results compared with lubricants formulated with group III base oils.
- Group III base oils produced by process of solvent dewaxing can be used in the formulation SAE 75W-XX, only in limited, exactly defined ratios.

References

1. W. TUSZYNSKI, R. MICHALCZEWSKI; Modern automotive gear oils - classification, characteristics, market analysis and some aspects of lubrication, Institute for sustainable technologies, Poland (2011), pp 297-322.
2. A study of automotive gear lubes; AMSOIL Drivetrain Division (2007).
3. T. MANG; Encyclopedia of Lubricants and Lubrication, Volume I, Springer, 2014, pp 727-758.
4. N. CANTER; Viscosity index improvers, STLE, pp 10-22, 2011.
5. B. SCHOBER, R.VICKERMAN, D.LEE; Controlled architecture viscosity modifiers for driveline fluids, 14th Annual Fuel & Lubes Asia Conference, 2008.
6. M. COVITCH, K. TRICKETT; How polymers behave as viscosity index improvers in lubricating oils, Advances in Chemical Engineering and Science, **5**, 134-151, 2015.
7. Technical publication of manufacturers of additives and viscosity modifiers.
8. ASTM and ISO test methods: ASTM D 2983, ASTM D 5293, BAS ISO 3104, BAS ISO 2909, ASTM D 5002, BAS ISO 3016.

Authors

Danka Šikuljak[1], Omer Kovač[1], Novak Damjanović[2]

[1]Oil Refinery Modriča, Vojvode Stepe 49, Modriča, Bosnia and Herzegovina;
e-mail: danka@modricaoil.com

[2] Optima Grupa, Banja Luka, Bosnia and Herzegovina

Received
30.8.2015.

Accepted
27.11.2015.