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EFFECT OF FOAMING ON THE ANTIWEAR PROPERTIES OF LUBRICATING OILS

Abstract
The foaming tendency of lubricating oils represents a serious problem in systems such as high-speed gear transmissions, pumping of high volume, and lubrication by spraying. Due to foaming, the lubrication is discontinuous, there is loss of lubricant due to overflow, which may result in mechanical damage and cavitation, with the decreased lifetime of the product and higher maintenance costs as consequences.

Various procedures that simulate operating conditions have been developed with the aim of evaluating the performance of lubricating oils in actual use.

The paper elaborates on various types of lubricating oils, for which the dynamics of creation and disappearance of foam has been analyzed, together with the tendency of adhesive-sliding wear at various speeds.

1. Introduction

Lubrication is the procedure that decreases the friction and wear of material, through the application of various types of lubricants. Internal friction of lubricating layers must be as low as possible, in order to enable unhindered operation of machines. Due to inappropriate lubrication, friction forces between the sliding surfaces may become such that excessive energy losses occur, together with overheating of operating engines; engines may begin to operate unevenly and noisily, which ultimately leads to wear and deterioration of individual machine elements. Due to the reasons mentioned above, a lubricant must have shear stability; good oxidation and thermal stability; corrosion and wear protection; good resistance to increased pressure, as well as good properties at low temperatures and resistance to foaming. In order to achieve satisfactory characteristics in application, appropriate additives are added to base oils. On the basis of knowledge regarding the physical and chemical properties of lubricants, it is possible to ensure reliable quality control in the course of production, and, in such a way, final formulations can fulfill increasingly strict product specifications. Functional and practical lubricant testing enables the full developmental and practical selection of lubricants for demanding lubrication areas. [1]

1.1 Foaming

One of the important physical properties of lubricants is the resistance of lubricant to the creation of foam. The creation of foam may be caused by detergent and anti-oxidation additives in the very formulation of a lubricant. In practical application, the foaming arises due to the excessive flow of lubricant; high pressures in inlet pumps; narrow canals in the area of application; and the penetration of air. In addition, the reasons may lie in insufficient quantity of lubricant, as well as the inappropriate geometry of sump. Foaming may be caused by the mixing of various types of lubricating oils, or by the penetration of lubricating greases, dust or water. [8]

Foaming results in discontinuous lubrication, increase of pressure in the area of application, loss of oil due to overflow, which leads to increasing costs and pollution of the environment. In addition, the capacity of lubricant to sustain the load is lower; lubricant oxidation is higher; the dissipation of heat away from the area of application is poorer. The result of such circumstances is the transformation of full-film lubrication into another type of lubrication: mixed and/or boundary lubrication. Such a type of discontinuous lubrication increases the possibility of friction and wear of machine elements, which is connected with higher maintenance costs.

By adding anti-foaming agents, the creation of stabile foam in oil is prevented. Anti-foaming agents act in such a way that they decrease the surface tension of air bubbles, breaking them into smaller bubbles, or destroying them on the surface, thus contributing to quick decomposition of foam. Various types of anti-foaming agents are in use: polyglycols, polyacrylates, quarterly ammonium salts; most frequently used are organic polysiloxanes-silicones. [2,9]

1.2 Wear

Wear is the gradual loss of material from the surface of a solid body due to dynamic contact with another solid body, fluid, and/or particles. [5]

There are four fundamental mechanisms of wear: [3,4]

- abrasion
- adhesion
- surface fatigue
- tribocorrosion

Abrasion is wear resulting in the removal of material, caused by hard particles or hard protrusions. Adhesion wear is characterized by a transfer of material from one sliding surface onto another in relative movement, due to the process of solid-phase welding. We distinguish three phases: the creation of adhesion pair in the area of contact of protrusions; severance of the adhesion pair; detachment of wear particle, or the particle remains permanently "glued", or welded onto another sliding surface (Fig. 1). Surface fatigue is a type of wear in which the separation of particles arises due to the cyclical changes of stress.

Tribocorrosion, or tribochemical wear, is a mechanism of wear in which the chemical or electrical-chemical reactions between the material and the environment are predominant.

According to the type of elements of the tribosystem, the type of contact, manner of load, and form of relative movement, we can distinguish between the following modes of wear: sliding wear; rolling wear; impact wear; fretting wear; abrasion; erosion; cavitation.

In order to test the resistance of lubricant to adhesion wear, we have used the "Four Ball", IP 239 apparatus. In this method, the bottom three balls are fixed in the holder, while the upper ball is rotating under a certain load. The load is gradually increasing, until the welding point is reached, or until the damage reaches a certain determined level. In addition, the wear on the bottom three balls can be measured in a certain time period (ASTM D 4172). Another method for testing adhesion wear is the "block on ring" method, ASTM G 77). [3,4]

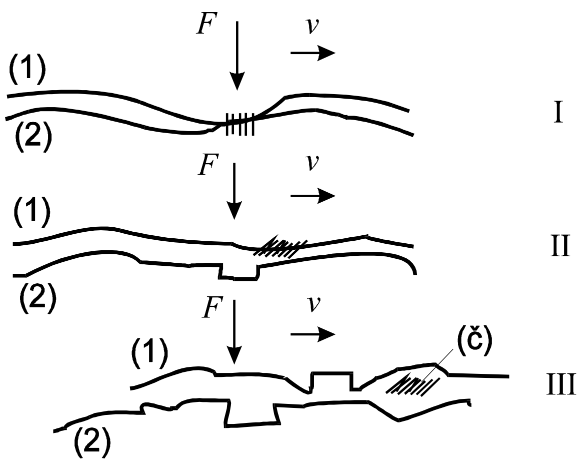


Figure 1: Unit event of adhesion [3], [4]

2. Experimental Part

2.1 Tested lubricants

Six various lubricants have been selected, showing a tendency towards foaming in application. The properties that were tested included the resistance to foaming, and the impact of lubricant foaming on load-bearing capacity, or on the appearance of adhesion wear in samples with and without the anti-foaming agent. The anti-foaming agent was silicon-based, polydimethylsiloxane (PDMS). [9] The fundamental properties of tested lubricants are outlined in table 1.

2.2 Testing of the resistance to foaming and results

The testing was performed according to the ISO 6247 method. This method is used to measure the tendency of growth and stability of foam at three different temperatures. Air is blown into the sample for 5 minutes; the volume of the created foam is measured, and expressed as the "tendency" of foaming. After 10 minutes, the volume of foam is again measured in the same sample, determined as the "stability" of foam. The result at room temperature is marked as Sequence I, after which the same procedure is repeated on the new sample at 93.5 °C (Sequence II), and the same sample is again tested at 24 °C (Sequence III). The characteristic that was tested was the foaming of lubricant without the anti-foaming agent, and the measurement was then repeated upon adding 15-30 ppm of anti-foaming agent.

Table 1: Tested lubricants

CHARACTERISTICS	TEST METHOD	A	B	C	D	E	F
Kinematic viscosity at 40 °C, mm^2/s	HRN EN ISO 3104	45.28	70.74	102.2	102.0	32.57	31.45
Kinematic viscosity at 100 °C, mm^2/s	HRN EN ISO 3104	8.86	9.88	11.05	15.10	3.56	5.30
Viscosity index	HRN ISO 2909	179	120	92	155	107	100
Pourpoint, °C	HRN ISO 3016	- 42	- 27	- 12	- 54	- 36	- 12
Flash point,°C	HRN EN ISO 2592	276	238	243	210	230	220
Appearance and color	Visual	Clear, brown	Clear, brown	Clear, brown	Clear, brown	Clear, brown	Clear, brown

A – Biodegradable synthetic-based hydraulic lubricant (HEES), B – Tractor oil (UTTO),
C – Circulating oil, D – Synthetic transmission gear oil (SAE 75W-90),
E – Hydrodynamic transmission oil, F – Neat metalworking oil.

Table 2: Results of foaming test

CHARACTERISTICS	A	B	C	D	E	F
Foaming (without AF) Sequence I, Tendency/stability, ml/ml Sequence II Sequence III	560 / 260 120 / 0 580 / 380	50 / 0 300 / 0 60 / 0	410 / 0 40 / 0 270 / 0	140 / 10 160 / 0 210 / 0	360 / 0 40 / 0 230 / 0	360 / 0 280 / 0 440 / 0
Foaming (with AF) Sequence I, Tendency/stability, ml/ml Sequence II Sequence III	150 / 0 100 / 0 40 / 0	0 / 0 20 / 0 0 / 0	10 / 0 40 / 0 0 / 0	15 / 0 80 / 0 10 / 0	10 / 0 20 / 0 10 / 0	0/ 0 20 / 0 0 / 0

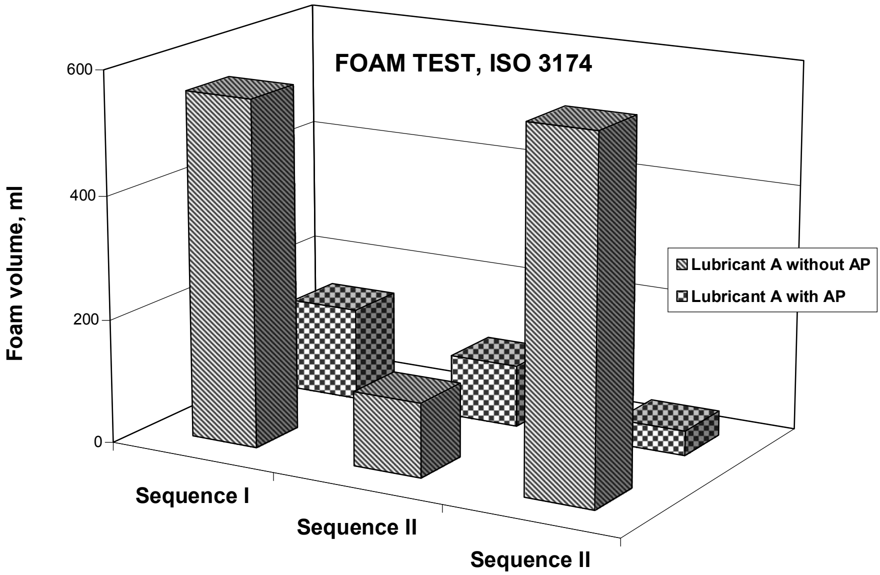


Figure 2: Foaming tendency of biodegradable hydraulic oil, without and with antifoam (AF)

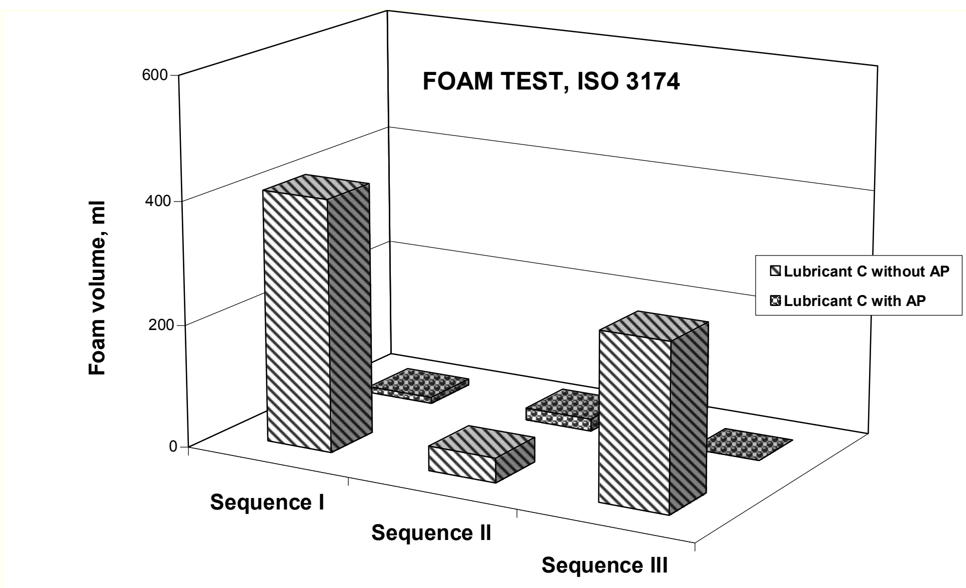


Figure 3: Foaming tendency of circulating oil, without and with antifoam (AF)

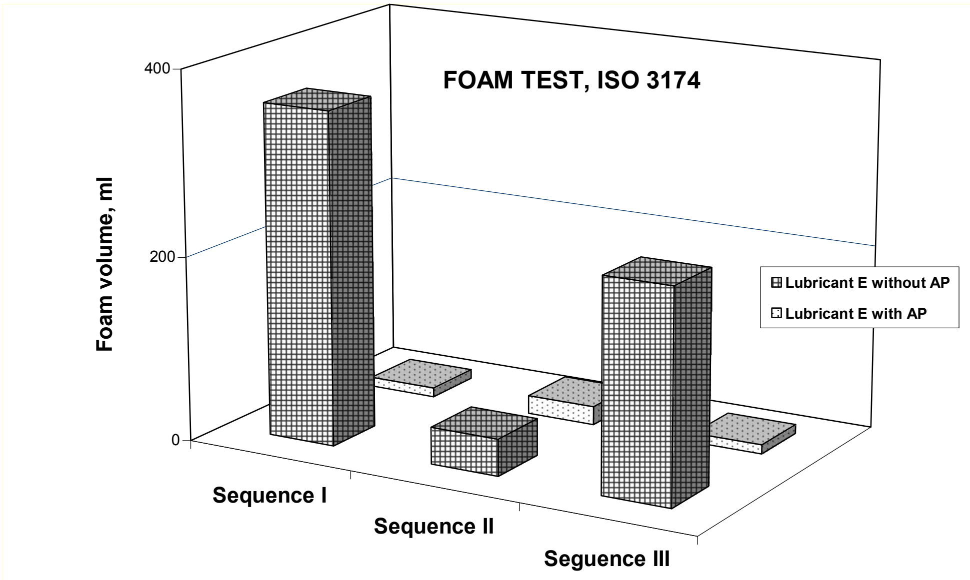
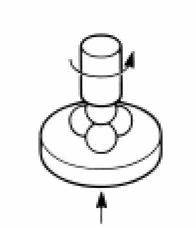


Figure 4: Foaming tendency of hydrodynamic transmission oil, without and with antifoam (AF)

2.3 Testing the resistance to wear and results

Lubricant samples were also subjected to mechanical testing of the load-bearing capacity of the lubricating layer, and of the resistance to adhesion wear (ASTM D 4172). In the Four Ball apparatus, one rotating and 3 immovable balls of same material and dimensions are placed in the shape of tetrahedron.



The ball system is located in a holder, which can be loaded, and it is filled with tested oil. When testing the medium diameter of wear, the load is standardized (1200 min^{-1}, 392 N, 75 °C, 1 h). This testing was performed at three speeds: 1200 min^{-1}, 1800 min^{-1} and 2200 min^{-1}. Upon the performed testing, the diameter of ball wear is measured.

The stronger the lubricating layer, the welding of balls takes place at higher load, and the wear is lower. With the increase in speed, discontinuous lubrication arises, and the wear is higher (table 3).

Table 3: Results of the Four Ball Wear test

CHARACTERISTICS	A	B	C	D	E	F
WEAR TEST – FOUR BALL (no AF) – Medium wear diameter, mm						
• 1200 min^{-1}	0.43	0.36	0.80	0.91	0.55	0.60
• 1800 min^{-1}	0.42	0.44	0.74	0.74	0.56	0.66
• 2200 min^{-1}	0.45	0.46	2.38	0.73	0.89	0.88
WEAR TEST – FOUR BALL (with AF) – Medium wear diameter, mm						
• 1200 min^{-1}	0.43	0.36	0.82	0.90	0.48	0.61
• 1800 min^{-1}	0.40	0.34	0.71	0.71	0.58	0.64
• 2200 min^{-1}	0.37	0.39	2.25	0.69	0.62	0.74

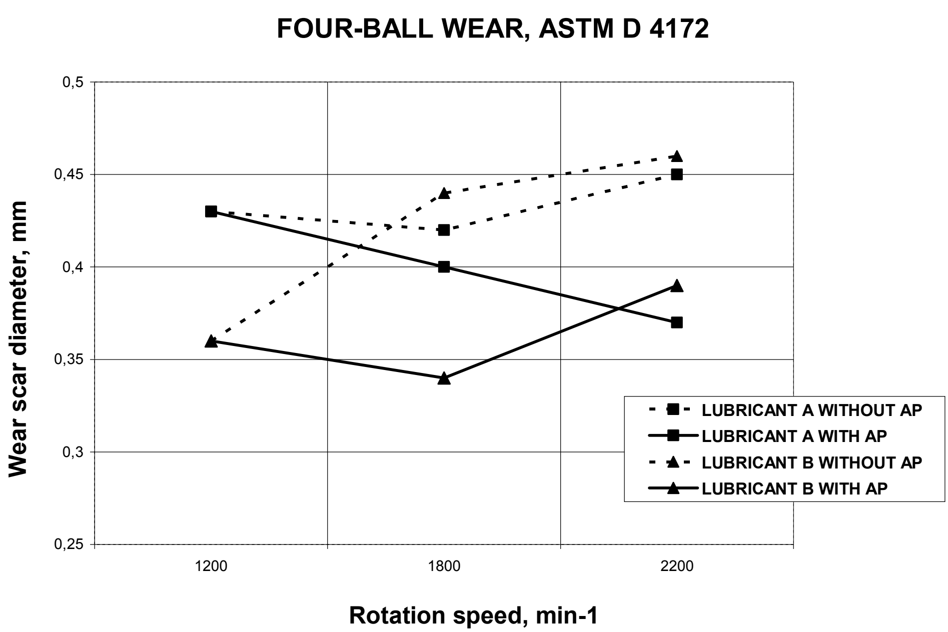


Figure 5: Anti-wear properties of biodegradable hydraulic oil and universal tractor oil, without and with AF

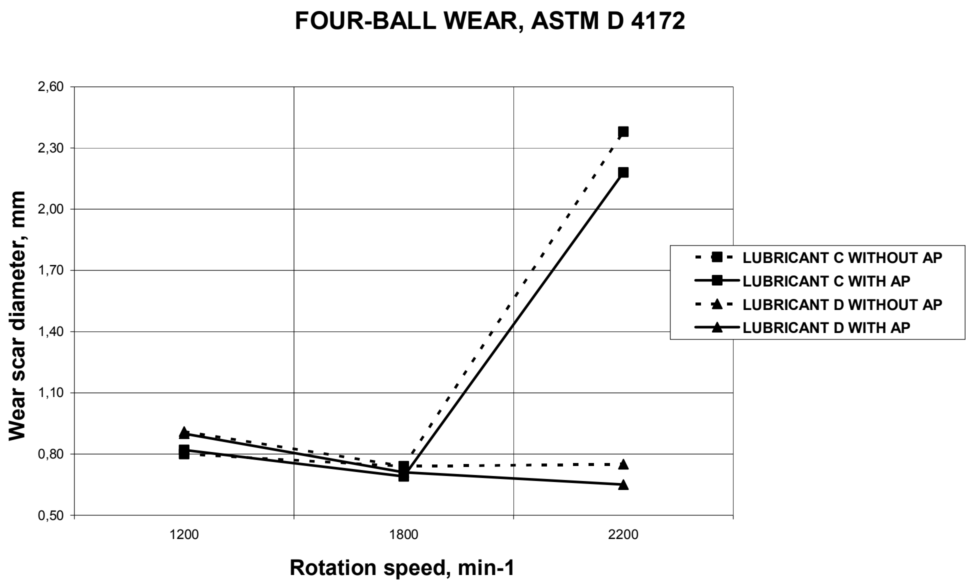


Figure 6: Anti-wear properties of circulating oil and synthetic transmission gear oil, without and with AF

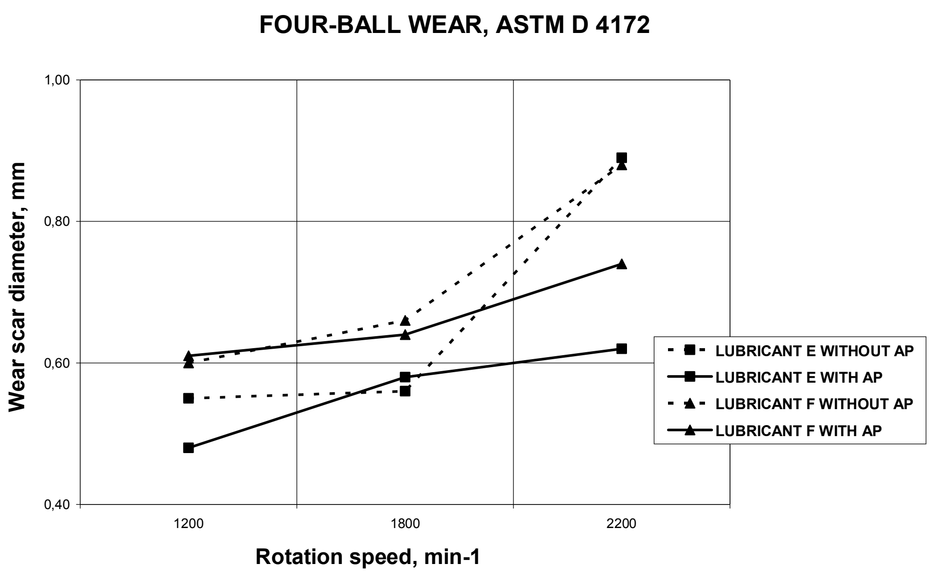


Figure 7: Anti-wear properties of hydrodynamic transmission oil and neat metalworking oils, without and with AF

3. Conclusions

Based on the performed testing of the characteristics of lubricant resistance to foaming and wear, we have reached the following conclusions:

- Lubricants with lower viscosity have a higher tendency of foam creation; lubricants with higher viscosity have higher foam stability;
- Excellent anti-foaming agent functioning can be observed in all types of tested lubricants;
- With the increase of speed in the wear test for lubricants with or without the anti-foaming agent, increasing wear occurs in most cases;
- The addition of anti-foaming agent decreases the wear;
- At lower speeds, full-film lubrication is still present, and there is no significant change in wear;
- At high speeds (2200 min^{-1}), significant difference in wear can be observed for lubricants with anti-foaming agent and those without – boundary lubrication;
- Better formulation of lubricants results in lower maintenance costs.

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