Serbian Tribology Society

SERBIATRIB '19

16th International Conference on Tribology

Faculty of Engineering University of Kragujevac

Kragujevac, Serbia, 15 – 17 May 2019

INVESTIGATIONS ON THE FRICTION IN ROLLING AND SLIDING BEARINGS DURING LUBRICATION BY RAPESEED OIL WITH NON TOXIC AND ASHLESS ADDITIVE

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Abstract: *Increasing of the environmental requirements to transport and industry poses to tribology a priority task related to the development of environmentally friendly lubricants and technologies. Vegetable oils and synthetic esters are most commonly used as biodegradable base oils. The fundamental constraints associated with their direct application are related to two parameters: stability towards oxidation and their contact characteristics, antifriction, wear and tear resistance. To increase oxidation stability, low unsaturated fatty acids contents are used, and the reduction of friction and wear is achieved by developing compatible composite additives towards the base vegetable oil.*

The present study presents results from a comparative investigation of friction characteristics and oil temperature in two tribosystems "Rolling Bearings" and „Sliding Bearing“ when lubricated with pure rapeseed oil and rapeseed oil containing 4% non-toxic and ashless additive . The new additive is designed for biodegradable base oils.

The research was conducted in tribology laboratories in Southern Ural State University, Chelyabinsk, Russia, and at the Technical University of Sofia, Bulgaria

Keywords: *tribology, coefficient of friction, rapeseed oil, AW/EP additives, rolling bearings sliding bearings*

1. INTRODUCTION

The enhancement of the ecological requirements to the transport and the industry poses to tribology a priority task – to elaborate environmentally friendly lubricants and technologies. The development of the tribology in the near future decades will be connected with solving issues and problems in the machines, the mechanisms and the technological equipment of a new generation, which should be in correspondence with the ecological requirements [1÷6].

During the last 10-15 years an intensive developent of the world production is observed as well as of the respective investigations, associated with ecologically clean lubricating materials and liquids, obtainable from renewable resources on the basis of vegetable oils and synthetic esters, as well as composites consisting of vegetable and mineral lubricating oils having a high degree of bio-degradability. The vegetable oils and the synthetic esters are most often used as bio-degradable base oils. Both kinds of oils have fundamental limitations, connected with their immediate application.

The main problems are connected with two parameters: stability to oxidation and their tribological characteristics i.e. antifriction, wear resistance and anti-tear properties. The reduced oxidation stability of the vegetable oils is determined by their chemical composition and in order to improve the stability one often uses oils having low contet unsaturated acids.

The second problem originates from a specific feature of the tribosystems, which is the fact that their functional characteristics, being dependent on the combined complex influence of many factors, and moreover these are changing during the course of theirexploitation. Researchers try to find a solution by elaborating compatible composite additives to the basis bio-degradable vegetable and synthetic oil [7÷9]. Until the present moment the utilization of such materials is reduced mainly to ecologically sensitive areas such as forestry, agricultural technics and construction.

The great interest in vegetable oils originates from their main advantages, compared to petroleum oils – they are non-toxic, quickly degradable, renewable sources and easily accessible. It has been established that in regard to their physical-chemical and tribological characteristcs the vegetable oils satisfy the exploitational requirements only under certain conditions. The vegetale oils - rapeseed, linseed, sunflower, caster oil, cotton palmitic etc. oils contain considerable amount of organic surfactant compounds (SACs) in the form of unsaturated fatty acids – oleic, stearic, eruceic, linolenic and others. During friction they form on the surfaces polymolecular layers of spatially orientated dipoles, which possess aisotropic mechanical properties – large pressure resistance and low resistance in the tangential direction.

These layers exert dampering action in the contact during friction, they hamper the direct interaction between the asperities and the intercalation of abrasive particles as a result of the wearing off process of the surfaces. In this way the organic surfactants in the vegetable oils appear to be natural antiwear additives, especially in the cases of mixtures of vegetable and mineral oils composites. The vegetable oils have a higher viscosity index (VI) – about 200 in comparison with that of the mineral oils. This criterion is extremely important for the mechanisms and the intensity of the tribological processes. The lower VI leads to intensification of the processes of aging of the oil and respectively enhaces the wear. It becomes clear from the above said that the vegetable oils do not need any addition of viscous additives.

The main problems in the efficient application of pure vegetable oils in contacts and joints originate from their low oxidative and thermal stabilities (thermo-oxidative stability) and their low-temperature properties [4÷13].

The aim of the present research work was to obtain comparable results on the friction characteristics in two tribosystems- “rolling bearing” and sliding bearing “Shaft-bushing” during lubrication with pure rapeseed oil and rapeseed oil, containing 4% non-toxic ashless additive AW/EP. The additive contains an ester of aconitic acid and hexadecyl alcohol (aconitic acid ester (AAE)). Additive’s chemical properties are similar to ones of vegetable oils, but the former contains a three-carboxylic groups acid in its molecule. As a result, AAE is more effectively adsorbed on metal surfaces than vegetable oil molecules. The new additive AW/EP is taylor-made for bio-degradable base oils.

2. FRICTION IN ROLLING BEARINGS

The moment of friction is being studied as well as the reduced coefficient of friction in the bearing junction in case of lubrication with rapeseed oil without any additive and rapeseed oil with 4% non-toxic ash-free additive AW/EP under identical conditions of friction – constant number of revolutions per minute and several values of the loading.

2.1 Device and methodology

The studies on the moment and on the coefficient of friction, carried out by means of DM 28M device, are shown in Fig.1 and Fig.2.

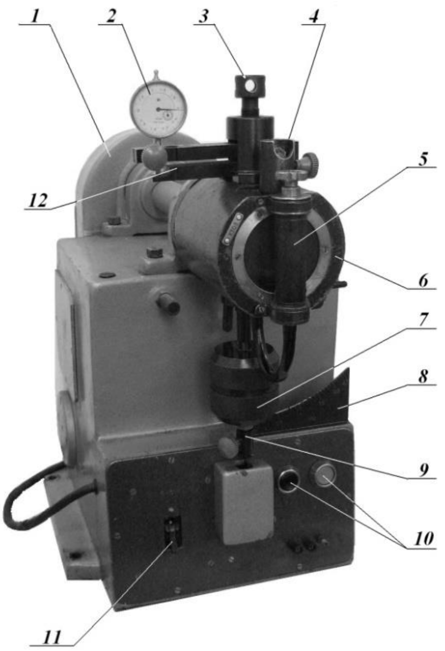

Figure 1. Outside appearance of device DM 28M

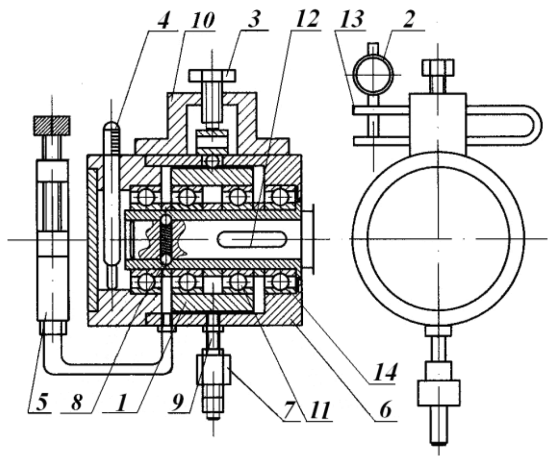

Figure 2. Bearing head of device DM 28M

The device consists of a body, in which a shaft is mounted (12), driven by means of belt transmission (1). At the end of the driving shaft the bearing head is attached (6), inside which there are four rolling bearings – two of them are in the middle (11) and the other two bearings are located at the two ends (14). The outer rings of the two middle bearings (11) are located in the common chamber. The outer rings of the two end bearings (14) are located in the body of the bearing head mounted tightly, whereupon they form close contact with the body of the head. The internal rings of the bearings (14) are attached by means of tightly screwed mount to the driving shaft (12). In this way the movement of the shaft (12) through the inner rings, ball pellets and the outer rings of the bearings is transferred to the body of the bearing head and this induces rotation in the direction of the rotating shaft. Thus during the rotation of the shaft the appearing friction moment drags the bearing head including the space location, where the middle bearings are attached. A pendulum (9) is attached stationary to the body of the bearing head. The magnitude of the friction moment is measured on the basis of the deviation of the pendulum (9) with respect to the vertical axis and the value is read on the scale (8), in units Nm. The adjustment of the pendulum in vertical position is done by means of the weight (7).

The normal loading is set on the middle bearings (11) by means of a screw for load adjustment (3) through dynamometric beam (13) and the value is read on the scale of the indicator (2) in units of Newton.

The lubricating oil is poured into the bearing node through an aperture, while its level is regulated by shifting the piston of the leveler (5). The temperature is measured using a thermometer (4), immersed in the oil.

The restriction of the abrupt rotation of the bearing head when the electric motor is switched on is achieved by restrictors.

The methodology for investigating the moment of friction and measuring the coefficient of friction consists of the following steps:

First the turnover number is set by adjusting the belt transmission (1). Lubricating oil is poured in (with or without additive) and then its level is adjusted by shifting the piston of the leveler (5). The pendulum is fixed in vertical position by means of the weight (7). The electric motor is switched on and the device is left to operate in this way for 5 minutes until a stable position of the pendulum is achieved and thereafter one reads the value on the scale (8), which corresponds to the magnitude of the moment of friction. By means of a distant turnover number metering device one can follow the number of revolutions of the shaft per unit of timeна aiming at measuring the magnitude of the friction moment upon reaching a constant number of revolutions. The friction moment is measured in regime without any loading, whereupon one reads the indications on the scale in 2 min intervals. The operator sets consecutively loadings of P_1, P_2, P_3,... by means of the screw (3) and measures the respective value of the moment of friction M_1, M_2, M_3,... The time interval for each loading value is 2 min. These operations are repeated in each next trial for the various lubricating oils. Upon changing the oil the bearing head is cleaned up by washing with gasoline or some other solvent and then it is dried up by warm air. All the trials are done at one and the same oil level – to the center of the bearing ball pellets, which guarantees identical conditions of lubrication in the bearing head.

The coefficient of friction μ is determined by the formula:

$$\mu = \frac{2M}{Pd} \qquad (1)$$

where d=40 mm is the diameter of the internal ring of the bearing.

2.2 Results and analysis

Using the so described methodology and device results were obtained on the moment of friction, the coefficient of friction and the temperature of the lubricating oil in the bearing unit in the case of lubricating with rapeseed oil without additive and with rapeseed oil, containing 4% of the additive AAE anti-wear/extreme pressure (AW/EP).

The experimental runs were carried out under identical dynamic conditions: number of revolutions n = 970 min^{-1} and under loading P = 25 N, 250 N, 500 N, 1000 N и 1250 N.

The measurements were made during a period of 2 minutes and total duration of friction 10 minutes. The initial temperature of the oil was 21°C.

The experimental data are listed in Table 1 and Table 2.

Table 1. Moment of friction, coefficient of friction and temperature of the oil in case of lubrication with rapeseed oil without additive

Lubrication with rapeseed oil without additive					
Loading, N	25	250	500	1000	1250
Moment of friction, Nm	0.2	0.3	0.4	1.2	1.5
Coefficient of friction	0.4	0.06	0.04	0.06	0.06
Temperature of the oil, °C	21.3	21.7	22.2	30	40
Time, s	120	120	120	120	120

Table 2. Moment of friction, coefficient of friction and temperature of the oil in case of lubrication with rapeseed oil with additive

Lubrication with rapeseed oil with additive					
Loading, N	25	250	500	1000	1250
Moment of friction, Nm	0.3	0.3	0.4	0.8	1.1
Coefficient of friction	0.5	0.1	0.04	0.05	0.04
Temperature of the oil, °C	21	21	21.5	22	26
Time, s	120	120	120	120	120

The dependence of the moment of friction on normal loading in case of lubrication with rapeseed oil without additive and with the additive is represented in Fig. 3, while the values of the respective coefficients of friction are given in Fig. 4.

The dependence has non-linear character for both types of oil. Under low loading up to 250 N the moment of friction remains constant and it has the same values for the two oils.

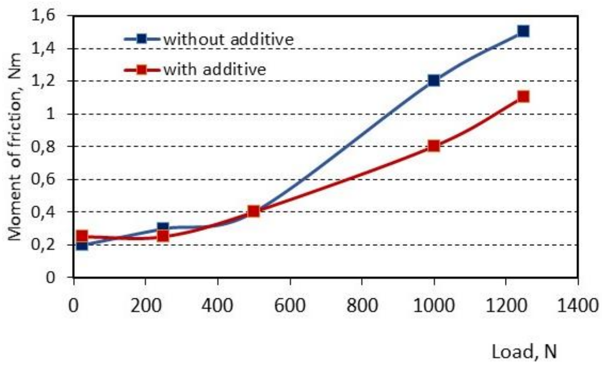

Figure 3. Dependence of the moment of friction on the loading in cases of lubrication with rapeseed oil without additive and with additive

When the loading is higher than 250N the moment of friction grows up non-linearly for both types of oil. One can see in Fig. 3 that for each value of the loading the moment of friction in case of rapeseed oil with additive AAE AW/EP is always smaller than the moment of friction for rapeseed oil without additive. The degree of decrease in the moment of friction when the loading is increase is only slightly different for the two oils. When the loading is 1000 N the presence of additive in the rapeseed oil leads to reduction of the moment of friction 1.5 times, while at higher loading 1500 N – 1.36 times.

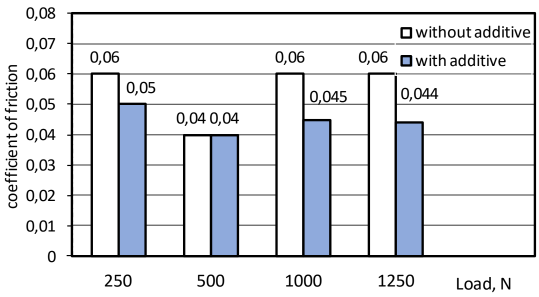

Figure 4. Diagram of the coefficient of friction in cases of lubrication with rapeseed oil without additive and with additive under different loadings

As one can see from the diagram in Fig. 4 the dependence of the coefficient of friction on the loading when lubricating with rapeseed oil without additive has non-linear character with well-expressed minimum under loading of 500 N. Under higher loading COF increases abruptly up to 1.5 times.

Upon lubrication with rapeseed oil with additive AAE AW/EP under higher loading of 500 N there is a little increase – 1.1 times and it remains constant. This could be explained by the fact that the presence of additive AAE AW/EP in the rapeseed oil leads to preservation of the lubricating film in the contact between the bearing rings and the ball pellets under higher loading. In case of lubrication with pure rapeseed oil the increase in COF upon increasing the loading is due to disruption of the lubricating film, increase in the local contact pressure as a result of the dominating mechanical component of the friction.

These results correspond to the nature of the dependence of the temperature of the two types of oils on the loading, represented in Figure 5.

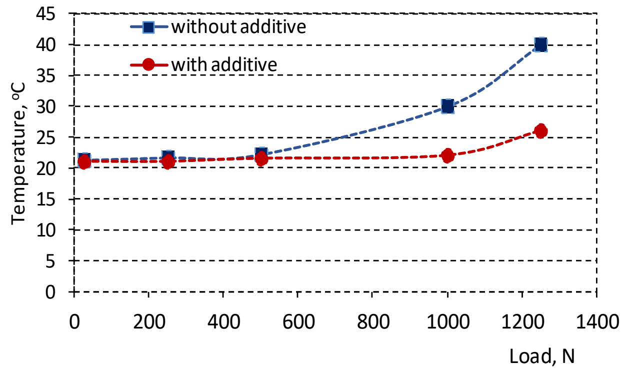

Figure 5. Dependence of the temperature of the oil on the loading during lubrication with rapeseed oil without additive and with additive

Up to loading of 500 N the temperatures of the two oils are the same and they are constant. Upon increasing the loading in case of rapeseed oil without additive the temperature starts to grow up. Upon increasing the loading 50 times, i.e. starting from 25N up to 1250N, the temperature of the rapeseed oil without additive increases almost 2 times - from 21,3 °C up to 40°C (Table 1), while in the case of rapeseed oil with additive AAE AW/EP the temperature increases 1.2 times - from 21°C up to 26°C (Table 2).

3. FRICTION IN SLIDING BEARING „SHAFT-BUSHING"

A comparative study was carried out focused on the coefficient of friction and on the contact temperature in sliding bearing „Shaft-bushing" in case of drop-wise lubrication with rapeseed oil without additive and rapeseed oil with additive AAE AW/EP at several different values of the normal loading – 250 N, 500 N, 1000 N and 1500 N.

3.1 Device and methodology

The experimental determination of the coefficient of friction is accomplished using the device DM 29M, represented in Figure 6 and Figure 7.

The device consists of a body (1), inside which a sliding bearing „shaft-bushing" is mounted; driving mechanism; loading mechanism, measuring device and a system for feeding lubrican oil. The shaft (14) is positioned on supports of two rolling bearings and it is driven by electric motor (12) by means of three-step wedge-belt transmission (13).

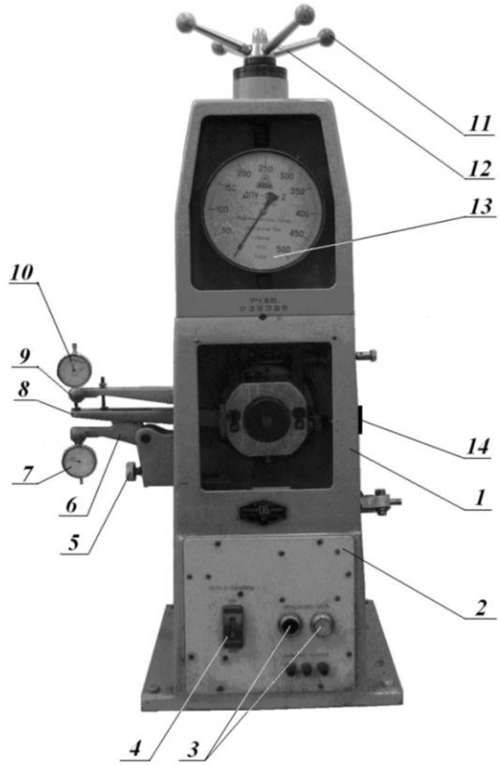

Figure 6. Photograph of device DM 29M

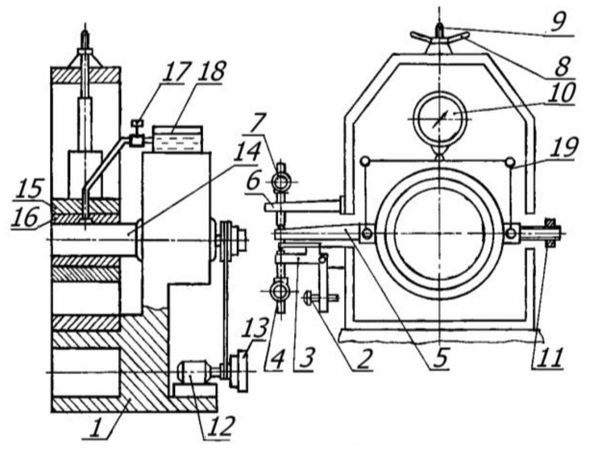

Figure 7. Scheme of device DM 29M

The tested bearing „shaft – bushing" is located in duraluminium body (15), whereupon the bronze bushing (16) is attached to a console at the end of the shaft (14).

The mechanism for loading of the bearing consists of loading screw (9) with a handle (8) and threaded bushing with sliding cotter, dynamometer (10), which is connected by a hinge with the threaded bushing, and loading framework (19). The framework (19) is connected by knuckle-joint to the body (15) and to the dynamometer (10). Upon rotating the handle (8) the screw (9) is shifted vertcally upwards and the loading framework (19) transfers the loading in the bearing from below upwards. The loading is measured on the scale of the dynamometer (10), graduated in Newtons - Fig.7. The Table 3 represents the technical characteristics of the tested sliding bearing.

Table 3. Characteristics of the tested sliding bearing.

Journal diameter	*d* = 60 mm
Bush length	*l* = 60 mm
Diametral clearance	*C* = 0.06 mm
Shaft (journal) material	Structural carbon steel 45 (GOST 8731-87); HRC = 35
Bush material	Lead bronze БрО5Ц5С5 (GOST 613-79); 60 HB
Lubricant	Rapeseed oil without and with 4% AW/EP additive

The measuring device consists of: measurement beam (5), attached to the body (15); fixed beam (6) with indicator (7); moveable beam (3) with measuring plate and indicator (4). The end-piece of the indicator (7) touches the measurement beam (5), while the end-piece of the lower indicator (4) touches the measuring plate, which is connected to the beam (5).

The system for feeding the lubricant oil to the bearing consists of oil bath (18), located in the upper part of the bodyand from there the oil flows down gravitationally at a rate of 30 - 40 drops per minute and along the pipeline with a valve (17) it enters the receiver channel of the bearing.

During the rotation of the shaft (14) in direction reverse to the clockwise direction under the effect of the moment of the forces of friction in the bearing the measurement beam (5) is bending and the arrow of the indicator (4) isdeviated to position δ.

The methodology for determination of the coefficient of friction is carried out in the following sequence: first the value of the revolutions per minute is set $n = 1350\ min^{-1}$ = const; the lubricating system is switched on by the valve (17) whereupon dropwise lubrication starts with rapeseed oil without/with additive; the normal loading value is set P_1 = 250 N by means of the loading screw (9); the settings on the two indicators are nullified (4) and (7); the electric motor is switched on and after a time period of operation 20 seconds at at nullified value setting on the indicator (7) on the fixed beam (6) the operator reads the indication δ of the indicator (4) on the moveable beam (3). Consecutively in time intervals of 40, 60......120 seconds one reads the indication δ.

The coefficient of friction f at any moment of operation is calculated by the formula:

$$f = k\frac{\delta}{P} \quad (2)$$

where: k=0.23 is the constant of the device.

The experimental run is repeated upon consecutively setting the loading value - P_2 = 500 N; P_3 = 1000 N and P_4 = 1500 N. The device enables carrying out the experimental runs at turnover numbers n = 500 min^{-1} and n = 2400 min^{-1}.

3.2 Results and analysis

The experiments were carried out under identical dynamic conditions: revolutions per minute n = 760 min^{-1} and loading. The results are recorded at time intervals of 2 minutes having total duration of the friction process 8 minutes. The initial temperature of the oil was 23,1^{o}C. The contact temperature was measured by means of laser infrared thermometer INFRARED.

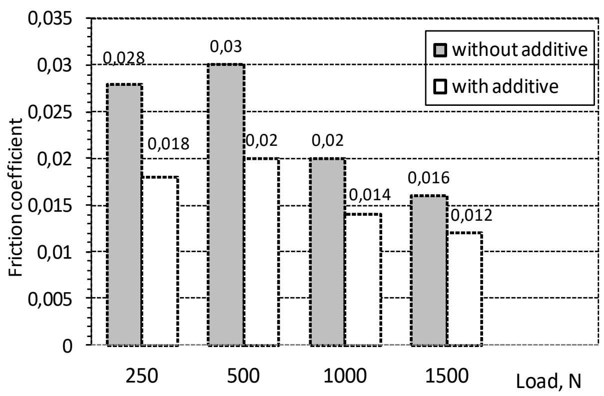

Figure 8. Coefficient of friction in cases of lubrication with rapeseed oil without and with additive under different normal loading

Figure 8 represents a diagram of the coefficient of friction, while Figure 9 illustrates the average contact temperature under different loadings in case of lubricating with pure rapeseed oil and with rapeseed oil having the additive AW/EP.

One can see from the diagram in Fig. 8 that under each loading value the coefficient of friction in case of lubrication with rapeseed oil having the AW/EP additive is lower than the coefficient of friction in case of lubrication with rapeseed oil without the additive.

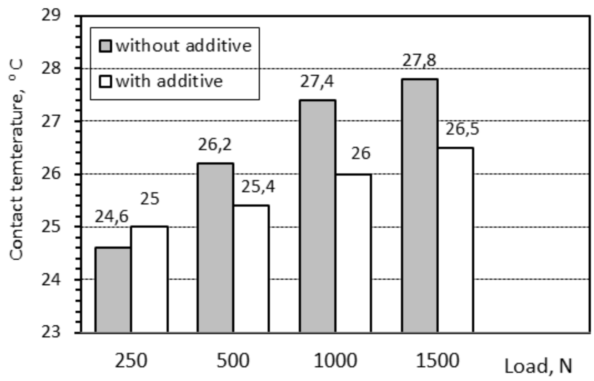

Figure 9. Average contact temperature (after 120 seconds) for rapeseed oil without and with additive under different normal loadings.

The dependence of the coefficient of friction on the loading has clearly expressed non-linear character. Upon increasing the loading the coefficient of friction grows up reaching the maximum value at P=500 N, and thereafter it is reduced. This character of the dependence is observed in the cases of both types of oils. The value of the maximum of the coefficient of friction for pure rapeseed oil is 0.03, while that for rapeseed oil with additive it is 0.02.

The influence of the additive AW/EP could be evaluated in first approximation based on the difference between the values of the coefficient of friction of the two oils. Under low loadings P_1=250N and P_2=500N this difference has the same value of 0.01. Upon increasing the loading the difference decreases: at P_3 = 1000 N it becomes 0.06, while at P_4 = 1500 N it is 0.04. This leads us to the conclusion, that under very high loadings one could expect that the influence of the additive will be reduced. This in its turn implies the necessity in the future to elaborate methodology and to study the influence of the additive upon the resource of rapeseed oil for various regimes of friction.

The obtained results are in harmony with the results on the changes of the contact temperature upon increasing the normal loading. One can see in Figure 9 that the presence of the additive AW/EP in the rapeseed oil leads to decrease in the contact temperature. During lubrication with rapeseed oil with additive under low loading P=250 N the temperature is with some 0.5^{o}C higher, but upon increasing the loading it remains lower under each loading with 1.3 ÷ 1.4 ^{o}C.

4. CONCLUSIONS

Comparative results have been obtained for the moment of friction, the coefficient of friction and the temperature of the lubricating oil under different loadings in rolling bearings and sliding bearing „shaft-bushing“ in the cases of lubrication with rapeseed oil without additive and rapeseed oil, containing 4% non-toxic ash-less additive AW/EP, which is designed for biodegradable base oils.

It has been found out that the presence of 4% non-toxic ash-free additive AW/EP in rapeseed oil leads to reduction of the moment of friction, the coefficient of friction and the contact temperature within the entire range of applied normal loading in both types of bearings. The difference between the coefficients of friction of the two types of lubricating oils upon increasing the loading is decreasing.

In the case of rolling bearings upon increasing the loading the coefficient of friction grows up for the pure rapeseed oil lubrication, while for the rapeseed oil with additive the coefficient of friction preserves a constant value. In the case of sliding bearing „shaft-bushing“under the conditions of boundary friction the coefficient of friction for both types of lubricating oils decreases with the increase in loading.

ACKNOWLEDGEMENT

The studies of the present research work have been carried out at the laboratory «Tribotechnika» in Southern Ural State University in Chelyabinsk, Russia and in the laboratory «Tribology» at the Technical University in Sofia, Bulgaria on the basis of Bilateral Cooperation Agreement between the two universities.

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