



ТЕХНИКО-ТЕХНОЛОГИЧЕСКИЕ ИННОВАЦИИ

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CALCIUM SOAP LUBRICANTS

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Abstract. The article studies the properties of calcium stearate (CaSt_2) and lubricants produced on its basis. These lubricants were prepared using sodium stearate and calcium chloride by subsidence from aqueous solutions. The CaSt_2 and the light fraction of crude oil were mixed together to obtain lubricating substances. The article shows that CaSt_2 had the melting temperature of 142.8 °C that is higher than the melting temperature of crude oil (128 °C). The compositions of obtained lubricants were studied with optical microscopes. The article shows that the sizes of dispersed particles amount to 1.88 μm and 0.11 μm for lubricants having 1 % and 2 % CaSt_2 concentration, respectively. As a result of wear trials, it was shown that the friction and wear coefficients of crude oil amounted to 0.099 and 1402 nm, respectively. For the lubricant with 1 % CaSt_2 concentration, these coefficients were reduced

to 0.0730 and 627.61 nm. Lower wear coefficient (540 nm) was obtained for the lubricant with 2 % CaSt₂ concentration. The CaSt₂ improved the lubricating property of crude oil but did not improve its oxidative and thermal stability.

Key words: lubricant, calcium stearate, crude oil, friction coefficient, melting temperature.

1. INTRODUCTION

A lubricant provides a protective film which allows for two touching surfaces to be separated, thus lessening the friction between them. Lubricating oil is a liquid lubricant that reduces friction, protects against corrosion, reduces electric currents and cools machinery temperature. It is most often used in the automobile industry and is applied to bearings, dies, chains, cables, spindles, pumps, rails and gears to make them run smoother and more reliable. Lubricating oil is a substance introduced between two moving surfaces to reduce the friction and wear between them. Lubricating oils consist of a liquid paraffinic or vegetable oil and surface active agents, antioxidants and anticorrosive additives. Metal soaps in pure form or dispersed in paraffinic oils are used as lubricants. Felder et al [3] used sodium and calcium soap coatings on steel wires for drawing the wires. Calcium stearate had good lubricating efficiency at low wire drawing rates [ibid.]. The possibility for the production of a motor oil with improved operating characteristics and a higher stability by applying composite additives has been studied by Palichev et al [8]. For this purpose two multifunctional additives, synthesized by them have been used. They used additives containing calcium stearate and calcium salts of nitrated polypropylene and oxidized paraffin, urea, ethylene diamine, stearic acid. The additives improved the anticorrosion, viscosity-temperature, antiwear and antisludge properties of the lubricant [ibid.]. The optimum concentration of the additive, which enables the production of a high-quality motor lubricant, has been found to be 5 % [ibid.]. Cutting oils were obtained by adding CaSt₂ to dry paraffin oil up to 5 % together with other additives [5]. Thus the gelation was prevented and an easily flowing cutting oil was obtained. Savrik et al [9] prepared lubricants using base oil, surface active agent Span 60 and zinc borate particles. They used 1 % Span 60 and 1 % zinc borate. Surface active agent Span 60 was found to be very effective in reducing the friction coefficient and wear scar diameter in

four ball tests. As surface active agents metal soaps are also used. Metal soaps are transition metal salts of the fatty acids and the alkaline earth elements. Although, the alkali salts of the fatty acids such as sodium and potassium are water soluble, metal soap is water insoluble but more soluble in non-polar organic solvents. Calcium stearate Ca (C₁₇H₃₅COO)₂, in short form CaSt₂ is the one of the important ionic surfactants of metal soaps. Calcium Stearate, is a non-toxic, white powdery substance. It is a calcium salt derived from stearic acid and is widely used in cosmetics, plastics, pharmaceuticals and lubricants [4].

Metal soaps can be obtained by neutralization of long chain organic acids with bases or by precipitation process. More ria et al [7] investigated formation of CaSt₂ from stearic acid and calcium hydroxide in different solvents and a complete conversion to CaSt₂ was obtained in ethanol medium [ibid.]. The precipitation process generally produces metal soap in powder form by the reaction of aqueous solutions of water soluble metal salt and fatty acid alkali metal salt at a temperature below the boiling point of water at atmospheric pressure. Filtering, washing, drying are the important steps in this method. Calcium stearate is produced in pure form by using this process [4].

Production of a lubricant by using a neutral base oil and calcium stearate is the aim of this study. The lubricating effects were tested by a four ball tester for this purpose.

2. MATERIALS AND THE METHOD

Materials

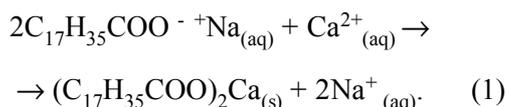
Calcium chloride, CaCl₂ · 2H₂O (98 %, Aldrich), and sodium stearate (NaSt), C₁₇H₃₅COONa (commercial product, Dalan Kimya A.S., Turkey), were used in the synthesis of CaSt₂. The acid value of stearic acid, used in the NaSt synthesis, was 208.2 mg of KOH/g of stearic acid and it consists of a C₁₆-C₁₈ alkyl chain

and with 47.7 % and 52.3 % by weight, respectively [4].

Spindle Oil from TUPRAS Izmir was used as base oil in the preparation of the lubricants.

Preparation of calcium stearate powder

Calcium stearate powder was prepared from sodium stearate and calcium chloride by precipitation from aqueous solutions according to reaction 1.



5.000 g (0.016 mol) of sodium stearate, (NaSt) was dissolved in 200 cm³ of deionized water in a stainless steel reactor at 75 °C. 1.7984 g (0.012 mol) of calcium chloride (50 % excess) was dissolved in 100 cm³ of deionized water at 30 °C and added to sodium soap solution at 75 °C. The mixture was stirred at a rate of 500 rpm at 75 °C by a mechanical stirrer for 30 min. Since the by-product, NaCl, is soluble in water the reaction media was filtered by using Büchner funnel and flask under 600-mm Hg vacuum level. To remove the NaCl completely, wet CaSt₂ was washed by 200 cm³ deionized water once and then, wet CaSt₂ cake was dried in a vacuum oven under 2 x 10⁴ Pa pressure. The KBr disc spectrum of the powder was taken with Shimadzu FTIR spectrophotometer. The SEM micrograph of the dried powder was taken with Scanning electron microscopy (Philips XL30 SFEG).

Lubricant preparation

1g of CaSt₂ and 100 cm³ spindle oil were mixed together at 160 °C at 880 revolution min⁻¹ rate for 30 minutes and then cooled to 25 °C by continuously stirring. At the mixing experiments, a heater and magnetic stirrer (Ika Rh Digital KT/C) and a thermocouple (IKA Werke) were used. The experiment was repeated with 2 g of CaSt₂ in 100 cm³ oil.

Lubricant characterization

The dispersion of CaSt₂ in base oil was observed by optical microscopy. The phase change

behavior of CaSt₂ and lubricants with increasing temperature was observed with an optical microscope equipped with a hot plate. The stabilities of the lubricants having different calcium stearate contents were determined by measuring the rate of settling calcium stearate particles in base oils. The chemical structures of calcium stearate and the prepared lubricants were investigated by FTIR spectroscopy. The tribologic behavior of the lubricants was tested with a four ball tester. Four ball tests were done using the four ball tester from DUCOM Corporation (Figure 1) to determine the friction coefficient and wear scar diameter of the lubricants. The test was performed according to ASTM D 4172-94 at 392 N and 1200 rpm and the test duration was 1 h. The wear scar diameter was reported as the average of the wear scar diameter of the three fixed balls.

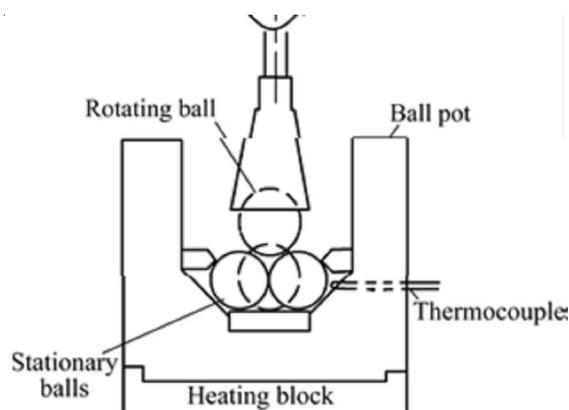


Fig. 1. Four ball tester

The visible spectrum of base oil separated by centrifugation from base oil was taken by using Perkin Elmer UV-Vis spectrophotometer by using base oil without any additive as the reference.

Optical microscope

Melting behavior of CaSt₂ in powder form and in dispersed form in the base oil on a microscope slide was observed by using the transmission optical microscope (Olympus, CH40) with a heated hot stage controlled by a temperature controller (Instec, STC 200C). The samples were heated at 5 °C/min rate from room temperature up to 190 °C. The photographs were taken with Camedia Master Olympus Digital camera.

3. RESULTS AND DISCUSSION

CaSt₂ powders

FTIR spectrum of calcium stearate powder obtained by precipitation process is shown in Figure 2. The characteristic peaks of calcium stearate at 1542 cm⁻¹ and 1575 cm⁻¹ were observed. These bands are due to antisymmetric stretching bands for unidentate and bidentate association of carboxylate groups with calcium ions [4; 6]. Antisymmetric and symmetric methylene stretching, and methylene scissoring bands ($\nu_a\text{CH}_2$, $\nu_s\text{CH}_2$, and $\delta_s\text{CH}_2$) were observed at about 2914 cm⁻¹, 2850 cm⁻¹ and 1472 cm⁻¹ respectively. These bands are due to the alkyl chain in the calcium stearate structure [4; 6].

The SEM micrograph of the CaSt₂ powder shown in Figure 3 indicated that the particles were

flat in shape and had a broad size distribution ranging from 200 nm to 1 μm . The average diameter of particles was 600 nm.

FTIR spectra of lubricants

The prepared lubricants were also examined by FTIR spectroscopy. Their FTIR spectra are shown in Figure 4. The peaks at 2918 and 2848 cm⁻¹, 1454 cm⁻¹ are due to stretching and bending vibrations of the methylene groups in base oil structure. The stretching and bending vibrations of the methyl group are observed at 2951 and 1385 cm⁻¹. At 3414 cm⁻¹ a broad peak related to hydrogen bonded OH groups is present. The antisymmetric stretching bands for unidentate and bidentate association of carboxylate groups with calcium ions at 1542 cm⁻¹ and 1575 cm⁻¹ are observed as small peaks in the spectra.

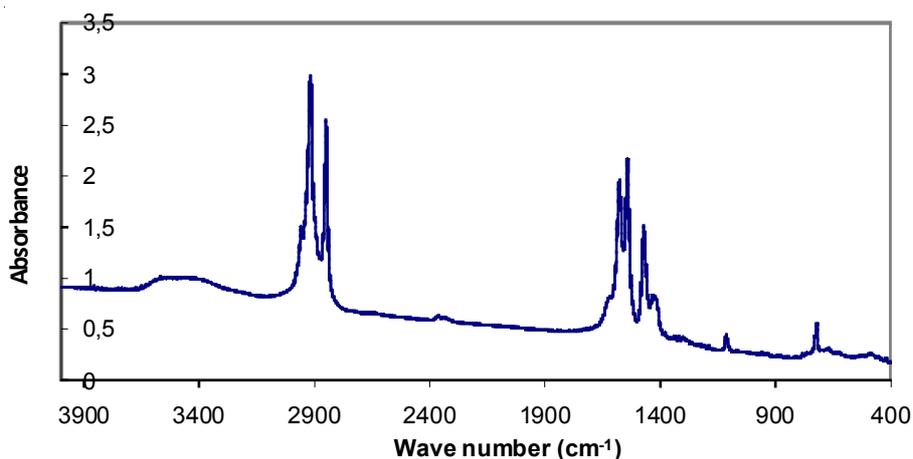


Fig. 2. FTIR spectrum of bulk CaSt₂

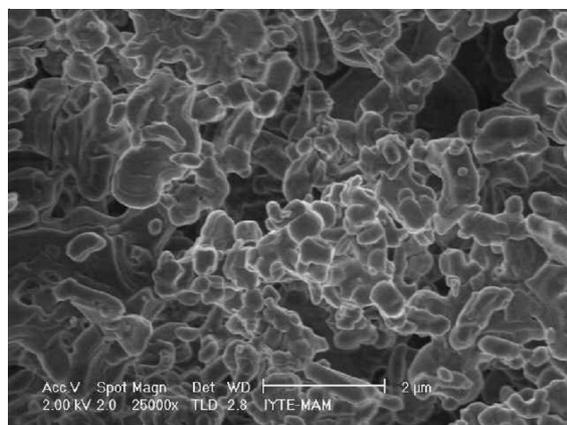


Fig. 3. SEM micrograph of CaSt₂ powder

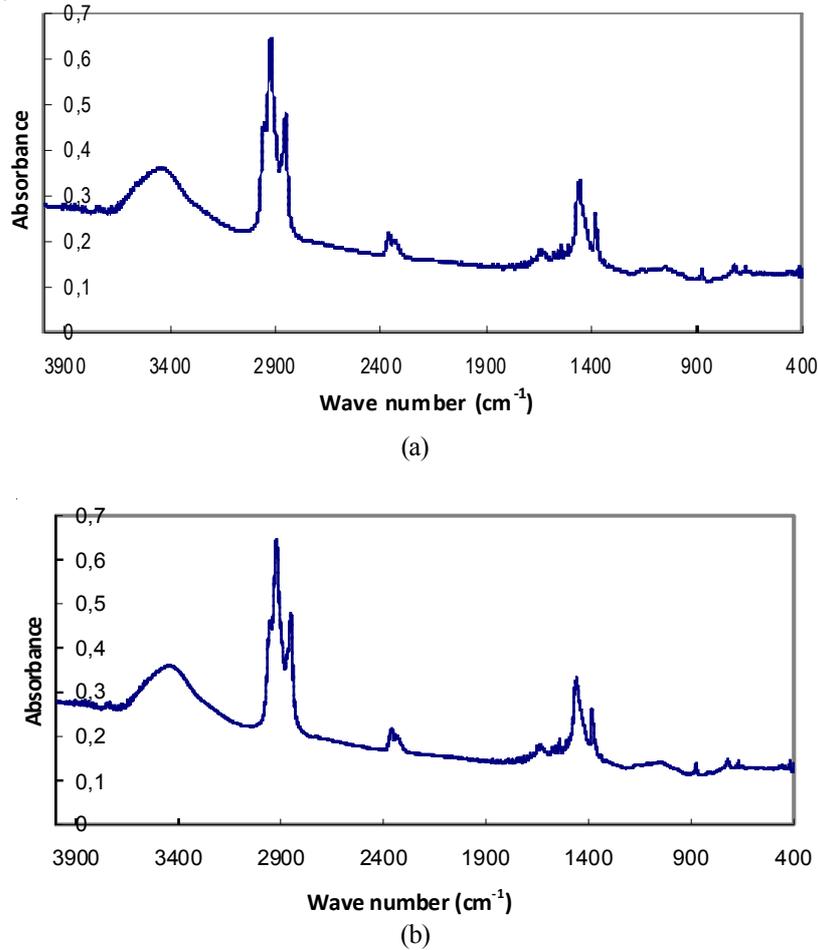


Fig. 4. FTIR spectra of lubricants with a. 1% CaSt₂ and b. 2 % CaSt₂

Stability of lubricants and the particle size of the CaSt₂ dispersed in base oil

The stability of the lubricant suspensions was determined by recording the height of the line separating the oil phase and the suspension phase. Due to gravity, settling the particles on the level of this line decreases continuously with time as seen in Figure 5. The settling velocity is directly proportional to the radius of the particle as shown in Equation 2 [2].

$$dx/dt = 2r^2(\rho - \rho_0)g/9\eta, \quad (2)$$

where: dx/dt is rate of settling (cm/s); ρ_0 is the density of medium (g/cm³), ρ is the density of particle (g/cm³), η is viscosity of medium (g/(cm.s)), r is radius of particle (cm), g is 981 cm/s².

The radius of particles was calculated from the slopes of the lines in Figure 6. The results

were evaluated for the settling of particles within 15 days. The oil density and viscosity used for the calculations are 0.86 g/cm³ and 0.35 g/(cm.s). The density of CaSt₂ is 1.12 g/cm³. The initial rate of settling was calculated as 0.188×10^{-7} cm/s and 0.635×10^{-12} cm/s for oils with 1 % and 2 % CaSt₂ respectively from Figure 6. Apparent radius of the CaSt₂ particles dispersed in base oil was 1.88 μ m and 0.11 μ m respectively for 1 % and 2 % CaSt₂ added samples respectively. The CaSt₂ particles were molten and recrystallized in base oil during preparation of the lubricant. Thus they have a different particle size than the original powder. At higher CaSt₂ content, the formed CaSt₂ crystals were in smaller size due to fast nucleation and slow growth of crystals. The gelation of CaSt₂ and base oil system is also another possibility affecting apparent size of particles.

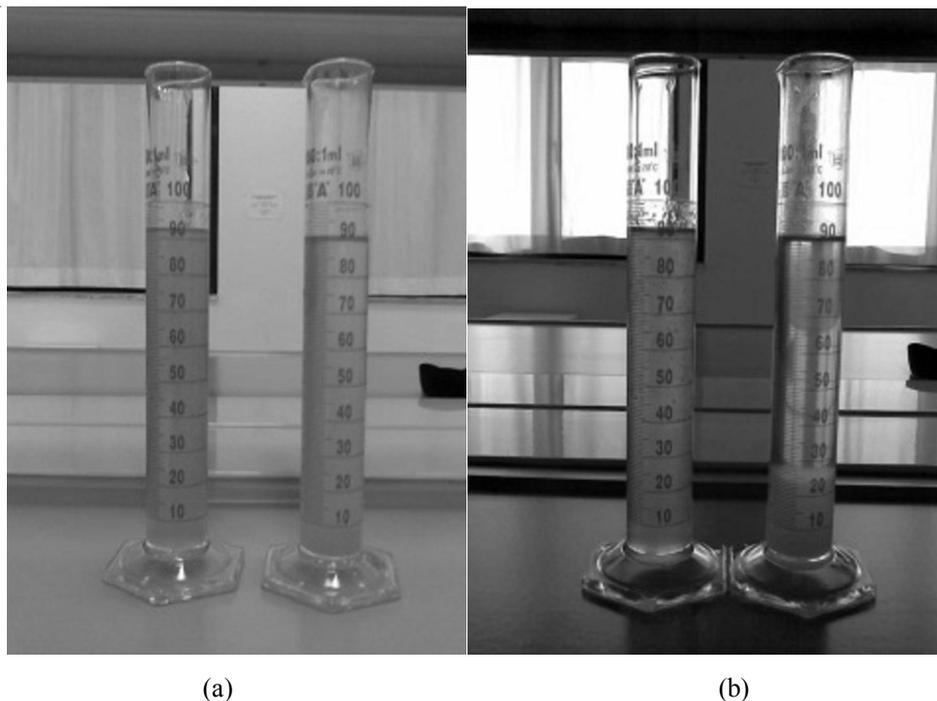


Fig. 5. Settling of CaSt₂ particles in base oil on the a. 1st day, b. 15th day after mixing

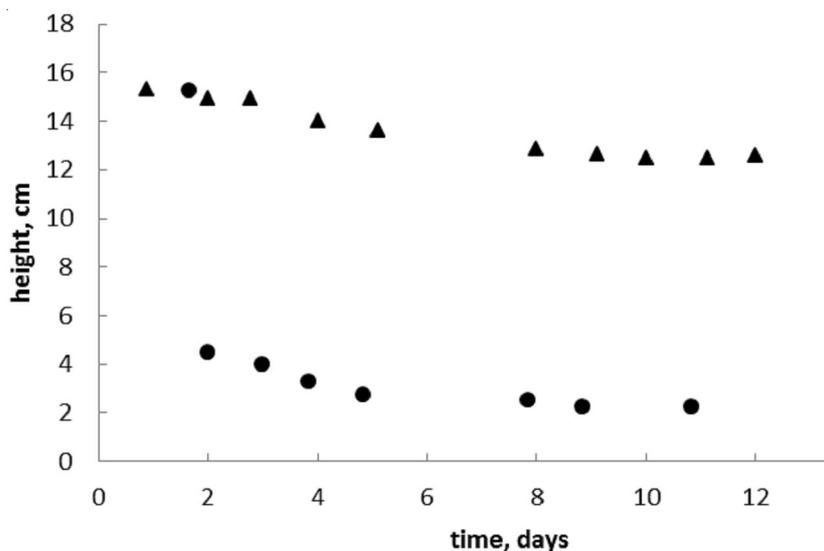


Fig. 6. The height of the boundary between clear base oil and CaSt₂ particles settling in base oil

Melting behavior of pure CaSt₂ and CaSt₂ in mineral oil

CaSt₂ powder melts at 120 °C as determined by DSC and at 148 °C by optical microscopy in a previous study [5]. In Figure 7 micrographs of the CaSt₂ powders before and after melting are seen. Before melting CaSt₂ appears as a white powder and on melting it is transformed into a

transparent liquid. It was found that CaSt₂ had a melting temperature of 142.8 °C by optical microscopy in the present study. CaSt₂ particles in base oil also showed a similar phase transition behavior as bulk CaSt₂. They were dispersed as particles in base oil at room temperature. The particles kept their shape up to 113 °C and they melted and mixed with mineral oil homogeneously at 128 °C as seen in Figure 8.

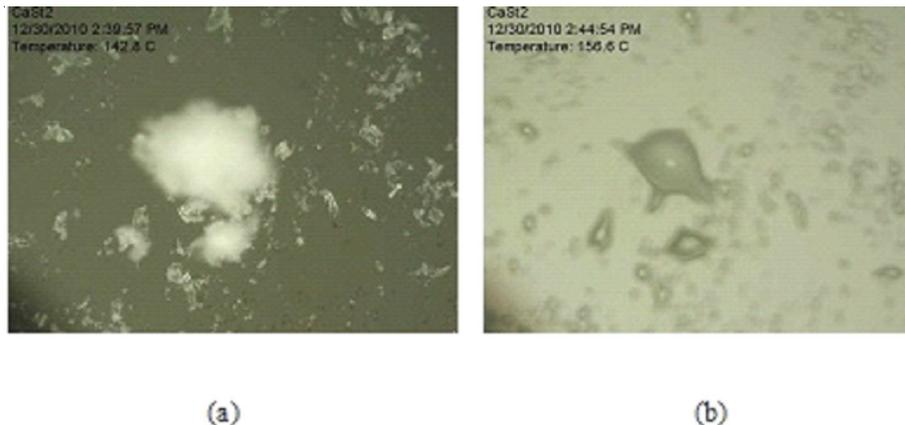


Fig. 7. Optical micrographs of CaSt_2 powder at a. 142.8 °C and b. 156.6 °C

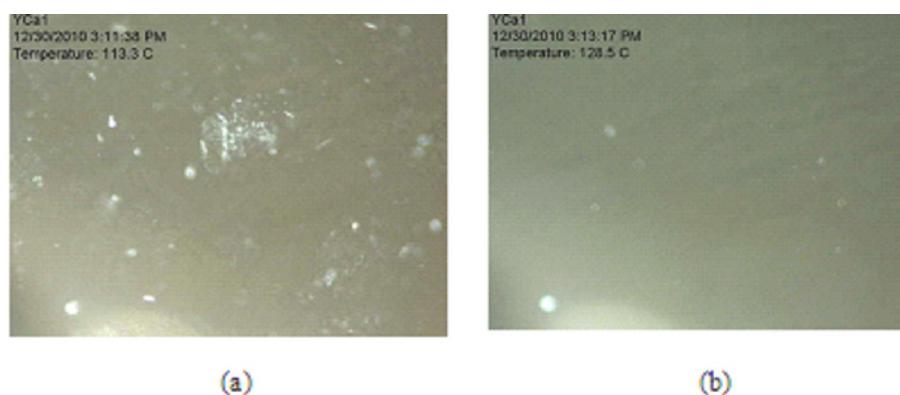


Fig. 8. Optical micrographs of CaSt_2 (1 %) dispersed in mineral oil at a. 113 °C and b. 128 °C

Friction and wear behavior of the lubricants

The lubricants with CaSt_2 efficiently decreased the friction and wear between metal surfaces. The four ball test results are shown in Table, wear scar's optical micrographs are seen in Figure 9. The friction coefficient and wear scar diameter of base oil 0.099 and 1402 nm were reduced to 0.0730 and 627.61 nm respectively for the lubricant having 1 % CaSt_2 . For 2 % CaSt_2 containing lubricant the friction coefficient and the wear scar diameter were 0.815 and 0.540 respectively. As the CaSt_2 content increased, better lubricating efficiency was observed. The four ball tests are done at 75 °C. At this temperature CaSt_2 is in solid form in base oil. However, by the kinetic energy of the rotating ball over fixed balls the temperature of the oil should have been increased to melt the CaSt_2 crystals in base oil and to cover the surface of

the balls by a smooth lubricating layer. The solid CaSt_2 particles similar to other nano-particles can also fill the crevices and holes on the steel surface reducing the friction and wear.

The effect of four ball tests on the color of the base oil

The lubricants change their color due to oxidation, hydrolysis and thermal degradation during its use. Contaminants from the eroding surfaces also change the color of the oil. The solid colorants in the lubricating oil can be filtered and the filter surface color can be measured [1]. In the present study the color change of the lubricating oils during four ball tests were investigated by visible spectroscopy. The visible spectra of the lubricants shown in Figure 10 were taken using the base oil as the reference. The base oil with 1 % CaSt_2 were lighter in color than the reference base oil as indicated by the negative

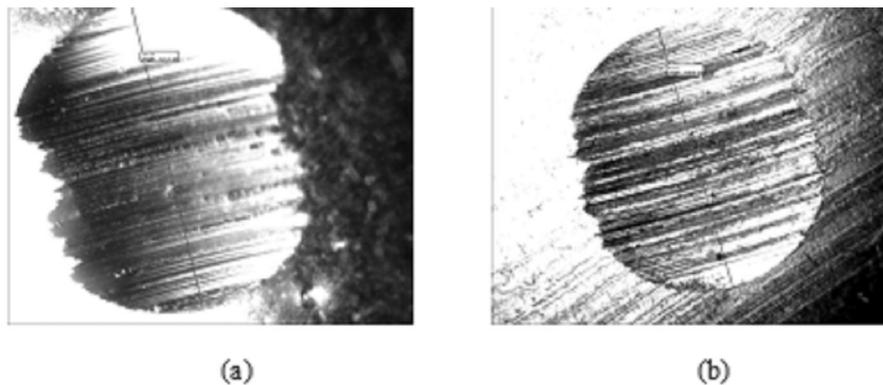


Fig. 9. Optical micrographs of the wear scar diameters of the one of the fixed balls of four ball tests for a. 1 % CaSt₂ and b. 2 % CaSt₂ containing lubricant

Friction coefficient and wear scar diameter of base oil and lubricants with 1% and 2 % CaSt₂

Property	Base oil [8]	Base oil with 1 % CaSt ₂	Base oil with 2 % CaSt ₂
Friction coefficient	0.099	0.0730	0.8150
Wear Scar Diameter, nm	1402	627.61	540.88

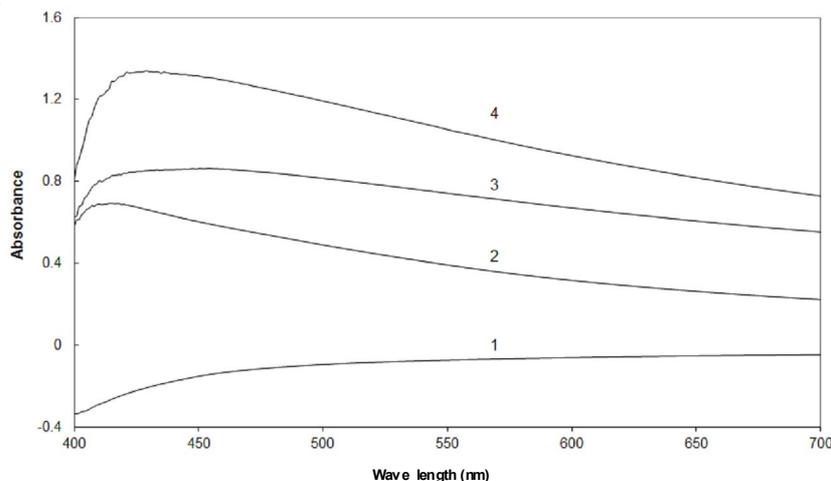


Fig. 10. Visible spectra of the base oil 1. before four ball tests, 2. after four ball tests for 1 % CaSt₂ and 3. before four ball tests and 4. after four ball tests for 2 % CaSt₂

absorbance values in Figure 10. CaSt₂ adsorbed the coloring material initially existing in the base oil. After four ball test, the base oil becomes dark yellow due to oxidation and crosslinking reactions in base oil. The base oil having 2 % CaSt₂ had higher absorbance values at all wavelengths and the absorbance was maximum at 420 nm. It also

had a darker color after the test. Thus, CaSt₂ improves the lubricating efficiency of the base oil, but it does not increase the oxidative and thermal stability. Adding antioxidants to the system would help the thermal and oxidative stability which could be the subject of further investigations.

4. CONCLUSION

Calcium stearate powder prepared from sodium stearate and calcium chloride by precipitation from aqueous solutions and Light Neutral Base oil were mixed together to obtain lubricating oils. It was found that CaSt₂ powder had a melting temperature of 142.8 °C and in the base oil it melted at above 128 °C. From rate of settling the particles in base oil the size of dispersed particles were found to be 1.88 μm and 0.11 μm respectively for lubricants having 1% and 2 % CaSt₂. The friction coefficient (0.099) and wear scar diameter of base oil (1402 nm) were reduced to 0.0730 and 627.61 nm respectively for the lubricant having 1 % CaSt₂. Lower wear scar diameter (540 nm) was obtained for lubricant with 2 % CaSt₂. Calcium stearate when added to base oil reduces the friction and wear of metal surfaces sliding on each other. It covers the cracks and grooves of the metal surface with a smooth film. Thus, it is an efficient lubricant additive. However, CaSt₂ did not increase oxidative and thermal stability of the base oil. Thus, further studies for the antioxidant selection should be made.

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ИННОВАЦИОННЫЕ СМАЗОЧНЫЕ МАТЕРИАЛЫ НА ОСНОВЕ КАЛЬЦИЯ

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Аннотация. В данной работе исследовались характеристики стеарата кальция (CaSt_2) и смазок на основе стеарата кальция. Смазочные материалы на основе стеарата кальция были подготовлены из стеарата натрия и хлорида кальция осаждением от водных растворов. CaSt_2 и легкая фракция сырой нефти были смешаны вместе, чтобы получить смазочные материалы. Было показано, что у CaSt_2 была температура плавления 142.8°C , что выше, чем температура плавления сырой нефти (128°C). С помощью оптических микроскопов были исследованы составы полученных смазок. Было показано, что размеры рассеянных частиц были соответственно $1.88\ \mu\text{m}$ и $0.11\ \mu\text{m}$ для смазок, имеющих 1 %-ную и 2 %-ную концентрацию CaSt_2 . В результате испытаний на износостойкость было показано, что коэффициент трения и размер изнашивания у сырой нефти были 0.099 и $1402\ \text{nm}$ соответственно, для смазки, имеющей 1 %-ный CaSt_2 эти показатели были уменьшены до 0.0730 и $627.61\ \text{nm}$. Еще меньше размер изнашивания ($540\ \text{nm}$) был получен для смазки с 2 %-ным CaSt_2 . CaSt_2 улучшил смазочное свойство сырой нефти, но не улучшил ее окислительную и термическую устойчивость.

Ключевые слова: смазка, стеарат кальция, сырая нефть, коэффициент трения, температура плавления.