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Research Article/Araştırma Makalesi

Investigating the Effect of Use of Vegetable Oils in Lubricants*

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Abstract
This study targeted at determining the effect of use of vegetable oils in lubricants. For this purpose some physical parameters (viscosity, viscosity index, pour point, flash point, density, color and total acid number tests) of canola, soy, olive, corn, hazelnut and castor oil were investigated. The same tests were made for 'Heavy', 'Light' and 'Bright Stock' base oils and the results were compared. Then physical properties of commercial hydrolic system lubricants were investigated and in order for to compare the results of both studies additives in the formulations were replaced with canola and castor oil. ASTM methods were used in the tests. While canola oil has provided positive results with respect to physical properties (viscosity, viscosity index and flash point) as additive, all other vegetable oils used except for castor oil gave positive results with respect to their physical properties in their use as base oils.

1. Introduction

Industrialization has marked a turning point in use of lubricants due to extensive use of machines. This in turn brought about the necessity of lubricants. According to the application areas the industrial lubricants market can be categorized in various ways. Gear lubricants, hydrolic lubricants and engine oils have been the most commonly used types of lubricants (Benedicto, Carouc, & Rubioa 2017.pp 99-116). This increasing need is met mainly by oil products. However, as crude oil reserves are on decline while the oil prices are on rise in the World and environmental concerns caused bio-based materials to be become preference of choice (Julian, 2011, pp 307-331). Development of bio-degradable and eco-friendly industrial additives from renewable resources have directed much attention to obtaining oils from natural resources (Jumat , Nadia & Emad. 2010,ss 519-530), (Sharma & Biresaw 2017, p. 450). Oil based products, which are named as lubricants, can enter environment and cause various types of pollution and toxic effect. Moreover, they also produce mass amounts of waste and thus discharge problems during lubricant change. When these two factors combine the amount of

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* **HIGHLIGHTS of the STUDY**
Determination of physical properties of some vegetable oils
Using vegetable oils as additive or base oil in lubricants

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lubricant which can enter and cause pollution and toxic effect reach an important level. Hence, the number of legal proceedings issued related with this issue has increased tremendously as well. Therefore, much effort is devoted to creating new efficient consumption ways and recycling strategies for resources in every field (Nagendramma P, Kaul S., 2012). Deveoping new lubricant formulations are one of such endeavors. The composition of lubricants relies mainly on base oils. Biodegradation and biotoxicity of of lubricants depend on the type of base oil used. Since these base oils are derivatives of crude oil cause major environmental problems upon their release in the environment. Therefore, recently use of vegetable oils as base oil in lubricant compositions has gained increasing importance (Kajdas, Karpińska, and Kulczycki 2010. p 239).

Vegetable oils are triglycerides obtained from plants via various methods. Their composition differs from crude oil based lubricants. Although fuels obtained from oil mainly consist of parafins and aromatic compounds vegetable oils are esters that fatty acids form with glycerine. These esters are called glycerides. 3 alcohol groups, which form glycerine molecule, form triglycerides upon esterification of fatty acids. Properties of vegetable oils depend on the type and amount of unsaturated fatty acids in triglycerides (Erdoğan, & Mohammed. 1997).

Studies on use of vegetable oils as lubricants in industry have gained increasing importance (Ebtisam &., 2017, v.26 **)**.. For instance while canola oil is used as hydrolics, tractor transmission lubricant and metal processing liquids, castor oil is mainly used as lubricant in gears and as grease (Tirth, & 2017, v 70). Olive oil has found application as automotive lubricant and soy oil is used in lubricants, biodiesel, ink and paints (Tirth, & 2017, v 70).

It is proven that lubricant property of vegetable oils is better than that of mineral oils. Lubricant property of lubricants based on vegetable oils and their derivatives is superior to that of mineral based lubricants and hence they are investigated as fundamental structure for lubricants and functional liquids (Kumar & Sharma, 2008 pp. 1-10). Since vegetable oils, which are excellent lubricants, are highly biodegradable, renewable and have negligible toxicity they have become the preference of choice in lubricant industry.

Vegetable oils generally have high flash point, high viscosity index, high lubrication power and less loss due to evaporation (Rani &., 2015, pp. 328-333). Vegetable oils that do not require additives are superior to mineral oils with respect to wearing and friction, load carrying capacity and lasts longer (Kozma, 1997, pp. 249-258), Remmele & Widmann 1999 pp.129-145). A 6 year field experiment made regarding performance, biodegradability and eco-toxicity of hydraulics based on canola oil showed that the agricultural machines which used vegetable oils could work 35.000 hours and 21.000 km more without any compromise on their mechanical features and the amount of leaking was not more than that caused by mineral oils (Remmele & Widmann 1999, pp.129-145). Lubricants solely formulized from vegetable oils have lower friction coefficient, equivalent load carrying capacity and better resistance than that the mineral oils, but their thermal and oxidative stability was found to be inferior (Fox & Stachowiak 2007, pp.1035-1046). Therefore, synthetic base oils have been the preference of choice in industrial applications fors o many years (Brown &., 2011, pp. 35.74).

Mineral oils are products obtained via blending of mineral oils of various viscosity or of synthetic base oils synthesized by chemical synthesis methods and additives that prevent corrosion, wearing, foaming and oxidation while regulating viscosity as well as providing physical and chemical properties such as dispersion and resistance to pressure (Rudnick, 2017). Mineral oils can be classified as engine and automotive gear lubricants, industrial lubricants, grease and lubrication preparations.

Base oils are the most important component of lubricant composition can be mineral, organic or chemical (Süleyman, 2018).Although base oils are mostly obtained from crude oil and are mineral based, they can also be vegetable based oils or animal fats. Crude oil, from which mineral based base oils are obtained, can be classified according to paraffinic, naphthenic and aromatic content (Mang & Dresel 2007). Base oils are carcinogenic (Schwarz, Dado, Hnilica, & Veverkov, 2015, pp. 37–45).

On the other side eco-friendly vegetable oils, which can provide desired properties upon modification, have started to attract more attention and the number of studies on improving their performance has increased. Among them *canola and castor oil* are reported as vegetable oils that are most commonly used as base oil due to its high oleic acid content (~ 60-70 %), positive effect on regulating viscosity, power and hydrolic transmission (Erhan, 2000). (Ştefănescu, Calomir, & Chiriță 2002, pp. 94-98). and thus has been reported to be a good alternative in industrial applications with respect to mineral oil lubrication capacity (Ştefănescu, Calomir, & Chiriță 2002, pp. 94-98). (Shaoning & 2016, pp. 346-352). *Soy oil*, which is the most commonly produced and consumed oil in the world, offers distinct advantages with respect to oxidation stability, high flame point (Erhan, 2000). (Carcel & 2005, pp 587-593). *Olive oil*, which is widely used in cosmetics, pharmaceutical industry, surface active agents, has been the new focus in lubricant industry. Despite being less cost effective due to its high content of linoleic acid and unsaturated fatty acid content olive oil it offers preferable lubricant properties (Maleque, Masjuki, & Sapuan, 2003. pp137-143). All vegetable oils have less friction value than mineral oils, but olive oil is reported to provide the best performance. Moreover, lubricating with vegetable oils provides better surfaces especially with steel surfaces (Carcel & 2005, pp 587-593). *Corn oil*, which is the most cost-effective oil among all other vegetable oils, has been used in surface active agents, cream, paint, ink industries as well as as anticorrosive agent on metal surfaces. *Castor oil* -a non-edible plant- has high oil content (~39.6 - 59.5 %) and it is rich in hydroxyl acid (risinoleic acid). The hydroxyl groups in the structure endows this plant with unparalleled physical properties such as high viscosity and relative density values, solubility in alcohols at any ratio and limited solubility in aliphatic oil solvents. Since the head group of the fatty acids in its content (COOH) is highly polar and contains water it caused increase in corrosion (ASTM D130, 2000), (ASTM D 665, 2006). However, this was overcome by using appropriate anticorrosive agents and it was proposed that castor oil can be used as a cost-efficient base oil when combined with appropriate additives (Jayadas & Prabhakaran, 2006, pp. 873-878). well besides itself being an effective additive for many oils (Rudnick, 2006).

Taking into consideration the advantages and limitations of both mineral and vegetable oil based oils this study targeted at investigating the potential usage of vegetable oils such as canola, soy, olive, corn and castor oils both as base oils and as alternative to chemicals used as additives. Thus some of their physical properties are investigated.

2. Materials and Method

2.1. Method

This study was conducted in three parts. In the first part, the physical properties of the vegetable oils were determined. In the second part, the same tests made for vegetable oils were repeated for mineral based oils. In the third part, usability of vegetable oils instead of additives, which play important role in the formation of mineral oils, was investigated.

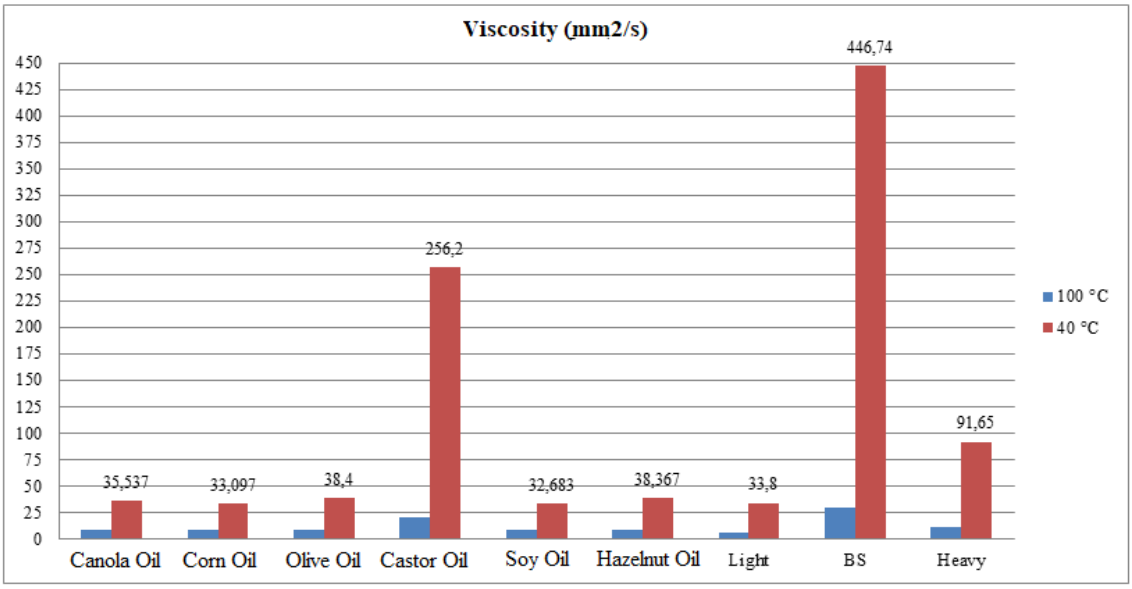
The physical parameters, which were investigated in the first part, were viscosity, viscosity index, flash point, flame point, density, total acidic number and corrosive behavior. *Viscosity test*s were made according to (ASTM D445, 1990). via Herzog HVM 472 at 100°C and 40°C. *Viscosity index test*s were made according to ASTM D 2270 (Standard Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 and 100°C) via Herzog HVM 472 to characterize the effect of temperature on the viscosity of crude oil products (ASTM D2270, 1998). *Flash point tests* were performed according to ASTM D 97 (Standard Test Method for Pour Point of Petroleum Products) via Lintech automatic flash point meter for to observe the lowest temperature when the liquid can flow (ASTM D97, 1965). . In each test approximately 30 g oil sample was used. *Flame point tests* were performed according to ASTM D 92 (Standard Test Method for Flash and Fire Points by Cleveland Open Cup Tester) via manual Cleveland open system flash and fire point equipment model Kdehler K 13900 for to observe the lowest temperature when the liquid would catch fire (ASTM D92, 1965). For each oil test fire was passed over the sample in every 2 °C increasefor 1 seconds at the temperature at least 28 °C before the expected flame point of the oil studied. The point when flame was observed in the oil is recorded as the flash point. *Density tests* were performed according to ASTM D 4052 (Standard Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter) via Anton Paar DMA 4500 densitometer (ASTM D4052, 1984). Approximately 0.7 mL of the lubricant was injected into the test tube of the oscillator. The density of the lubricant is determined by comparing the difference in the oscillation frequency that the change in the weight of the test tube causes with the calibration graph. The *total acid number* (TAN), which indicates the acid content of the lubricant, was determined via TAN tests were performed according to ASTM D 664 (Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration) via Schott equipment (ASTM D974, 2012). The sample is dissolved in toluene and isopropyl alcohol mixture and is titrated with potassium hydroxide. The result obtained from the titration is used in calculating the TAN. *Copper strip corrosion test*s were performed via Polyscience equipment according to (ASTM-D 130, 2000). The test bath of the equipment is filled with monoethylene glycol + oil upto the point just below the lowest point of flow tube and is maintained at 100 +/-1 ^{o}C. 30 mL samples were placed in the test tubes and the test tubes were placed in the test bomb. The capped test tubes with felt lining could stand up to 100 psi. Following this the equipment was tightly closed and was kept at 100±1°C for 3 hours. Then the copper strip was removed and was gently dried with filter paper without rubbing. This strip was then compared with the color standard of ASTM copper strip (ASTM D 130, 2018). In the second part, the results obtained from the vegetable oils were compared with those obtained from Heavy, Light and Bright Stock (BS) which are mineral based oils. In third part, in order to determine whether the vegetable oils could be used as base oils the hydraulic oil system obtained from Anton Parr was used as reference oil and instead of the chemical additives in this oil canola and castor oil were added at the amounts determined in this study. The changes in the physical properties were recorded.

3. Results and Discussion

Part I- Tests made for to investigate whether vegetable based oils can be used as base oils.

Viscosity Test Results of the materials were calculated at 40 °C and 100 °C and the results are presented in Figure 1.

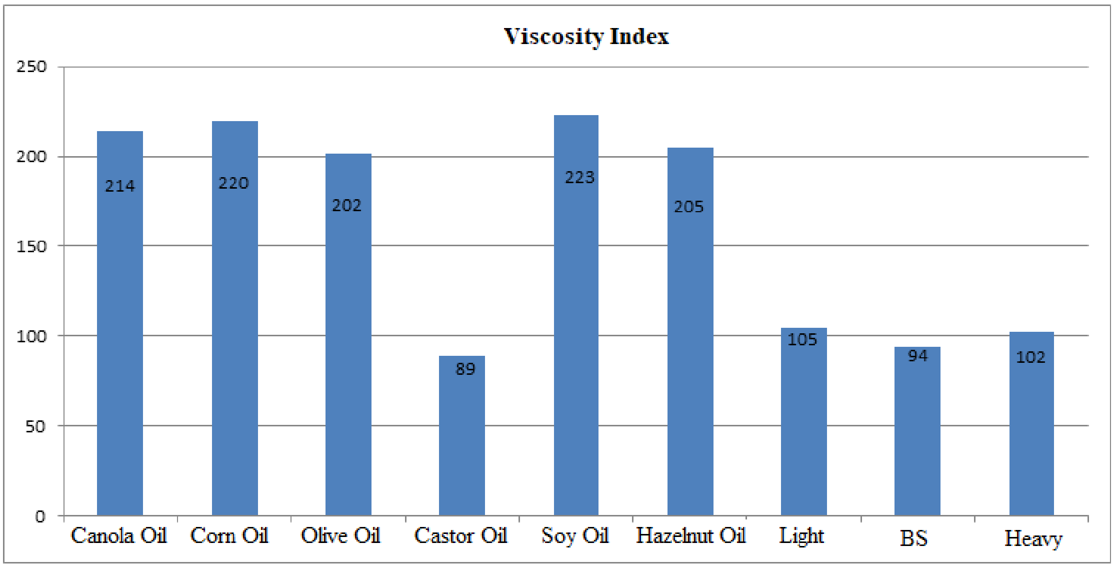
Figure 1. Viscosity values of the oils tested.



It was observed that at 40 °C the viscosity values of canola, corn, olive and soy oil and of Light oil, which is a mineral based oil, was in the range from 30 mm²/s to 40 mm²/s. While BS had a very high viscosity, which was 446,74 mm²/s. Contrary to other vegetable oils at 40°C castor oil had high viscosity, which was 256,2 mm²/s, and Heavy had a viscosity of 91.65 mm²/s. When the viscosity values were investigated at 100 °C it was observed that except for BS viscosity of all other oils ranged between 5-11 mm²/s. It was observed that increase in temperature considerably decreased viscosity.

The results of the **viscosity index studies** of the oils investigated are presented in Figure 2.

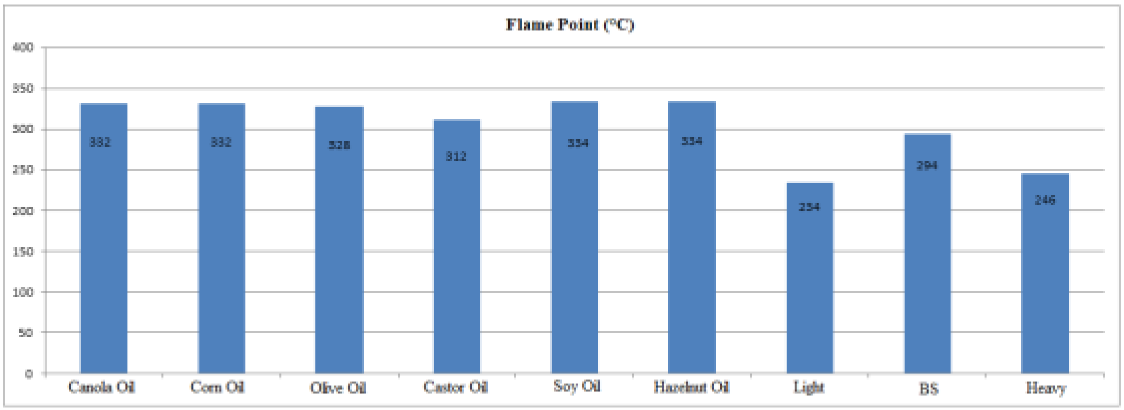
Figure 2. Viscosity index values of oils tested



Viscosity values of all vegetable oils except castor oil were observed to lie in the range 200-225. According to the API standards the viscosity values of Light, BS and Heavy were found to be appropriate with the values of Group I base oils. These values indicate that except for castor oil viscosity of all vegetable oils do not change much with change in the temperature. This is property is an advantage of vegetable oils.

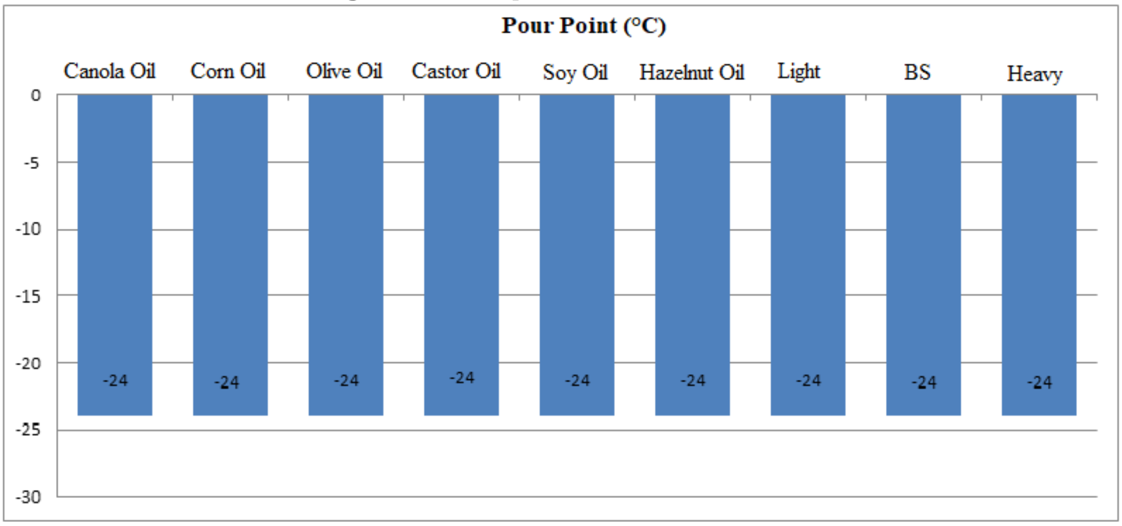
As is observed in Figure 3 flame points of vegetable oils were observed to be higher than those of mineral based oils. This is because of the low vapor pressure and low volatility of vegetable oils since they have strong intra-molecular interactions among their molecules. This indicates that vegetable oils can be used both as lubricants and as additives in base oils.

Figure 3. Viscosity index values of oils tested



When pour points of the vegetable oils used in this study were investigated, as shown in Figure 4, it was observed that they were the same as those of mineral base oils (-24 °C).

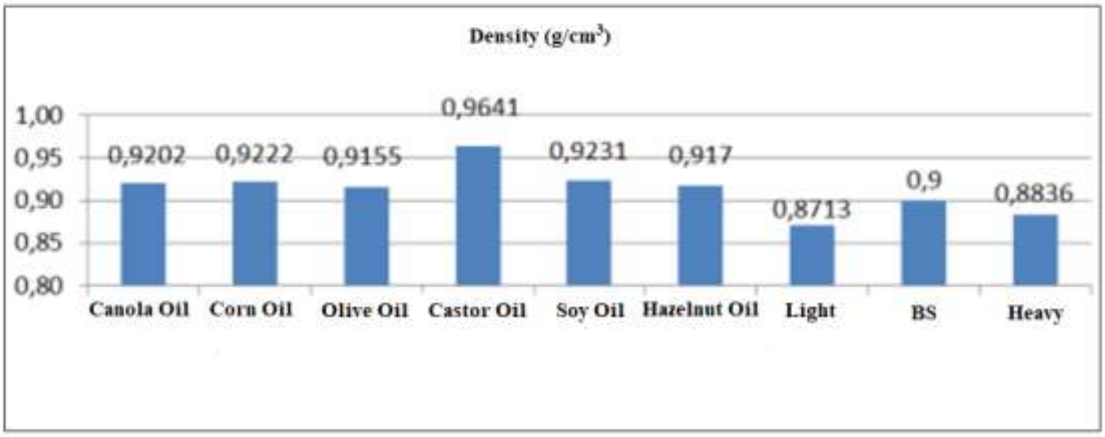
Figure 4. Pour points of the oils tested



The pour point test results indicate that vegetable oils can be used as base oils.

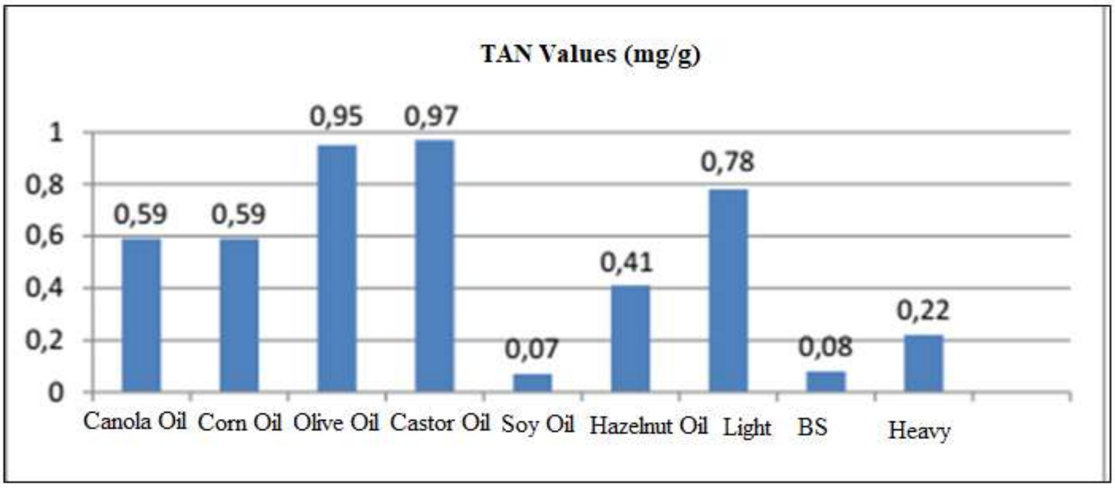
Density study results as expressed in Figure 5 showed that mineral based oils are less dense than vegetable oils and the density of castor oil is more than other vegetable oils.

Figure 5. The density values of the oils studied



Total acid number (TAN) studies indicate that except for "Light" mineral based oils have TAN values lower than those of vegetable oils whereas soy oil and hazelnut oil have TAN values of 0,07 mg/g and 0,41 mg/g, respectively. As can be seen in Figure 6 these values are less than the Tan values of mineral oils. BS with a TAN value of 0,08mg/g is closest to soy.

Figure 6. Total acid numbers (TAN) of the oils studied



However, these values cannot be used for deriving any conclusion regarding the oxidative stability of vegetable oils, because oxidative stability can be evaluated via TAN values only after the oils are used for a long time. It is reported that after long periods of usage molecular degradation will happen due to oxidation and the free fatty acids will be formed. These fatty acids would increase the TAN value (ASTM D 664, 2018).

Copper strip corrosion test results indicated that oils showed good performance against corrosion.

Part II targeted at investigating the possibility whether vegetable oils can be used instead of additives in hydraulic oils. Commercial hydraulic oil, the content of which is presented in Table 1, was prepared as a reference material.

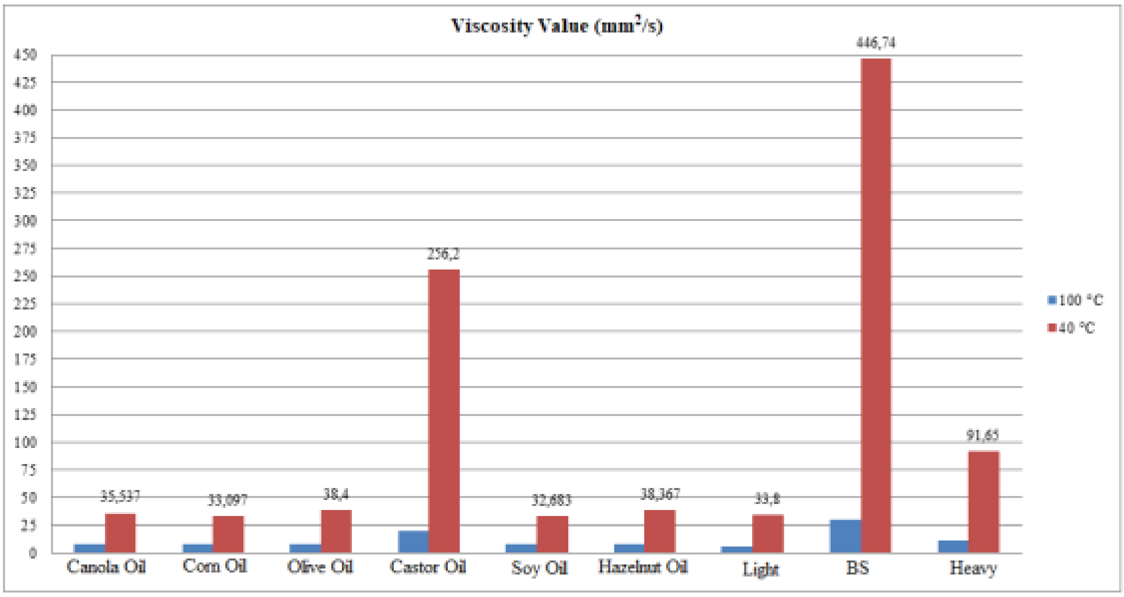
Table 1. Base oil and additive contents

Component	Amount (g)
Heavy	320
Light	176
Additive X	1.75
Additive Y	2.25

In this hydraulic oil formulation additive X functions as an agent to lower the pour point while additive Y functions as an agent against foaming. First viscosity, viscosity index, density, flame point, pour point, copper corrosion strip and TAN tests were made for these lubricants. The results were used as reference values. Then the additives used in these formulations were removed and they were replaced with canola and castor oils at amount equal to the amounts of the additives which was 4 g. Canola oil was preferred in this study as it is the most commonly used oil in research with vegetable oils. Castor oil was not preferred as it differed much from other vegetable oils used in this study.

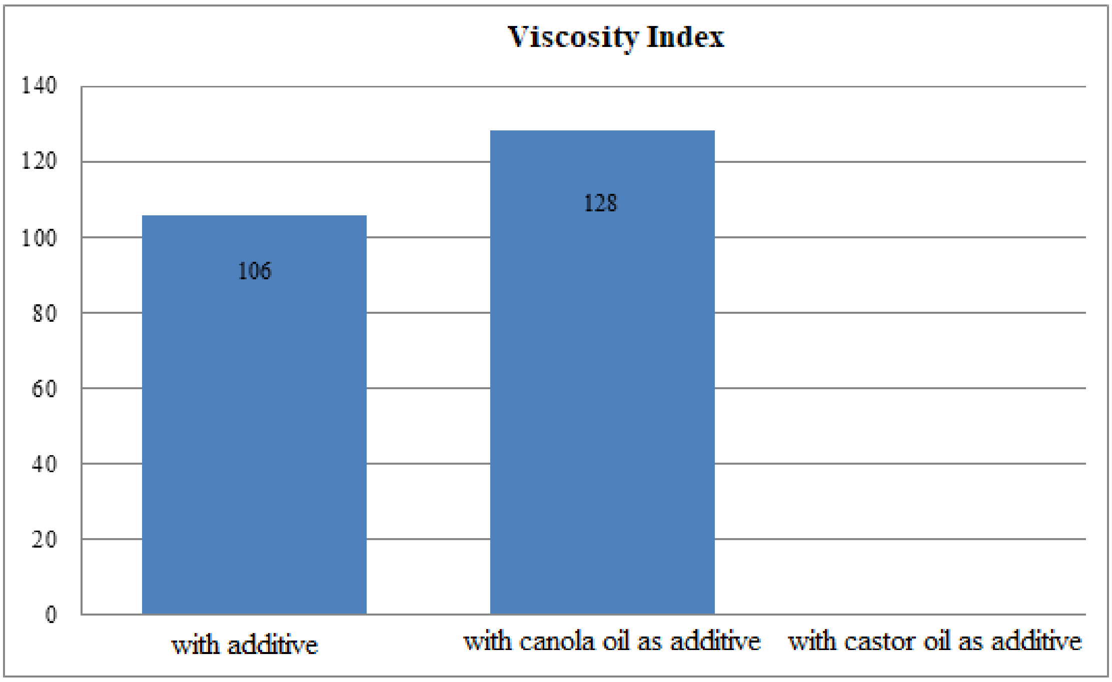
Viscosity and viscosity index studies, as can be seen in Table 9, reveal that temperature affects viscosity values.

Figure 9. Viscosity values of oils used



It is known that there is no additive in the formulation which can affect viscosity. Effect of presence of vegetable oils as additives on viscosity of formulations is presented in Figure 10.

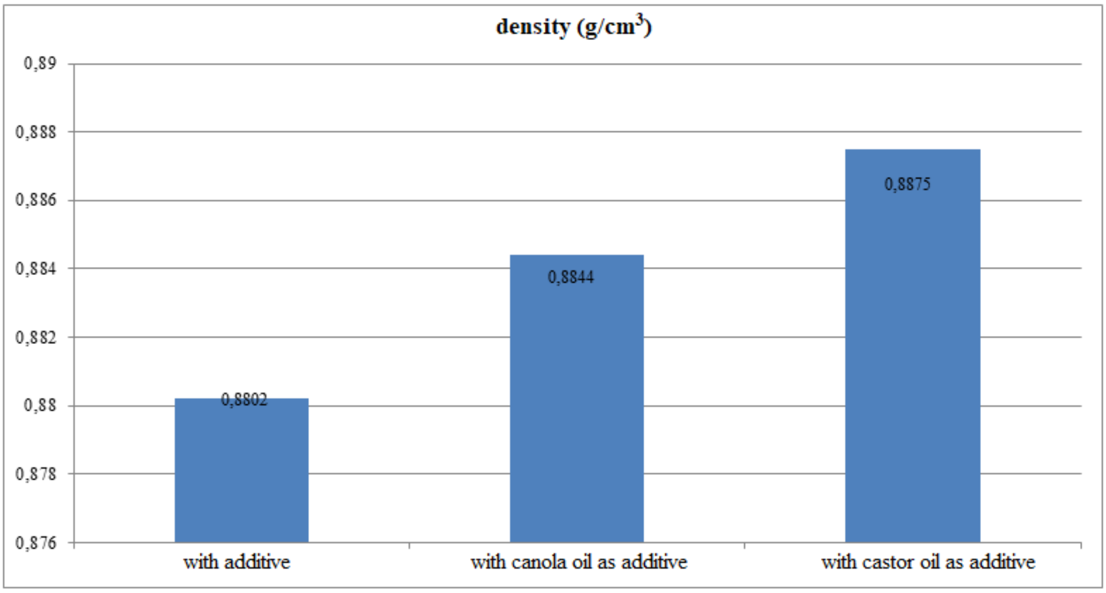
Figure 10. Viscosity index values



It can be seen in Figure 10 that both at 100 °C and at 40 °C canola oil decreases viscosity while castor oil increases viscosity at both temperatures. This is an expected situation since the viscosity value of canola oil is lower than that of mineral based oils used in the formulation. As can be seen in Figure 10 the viscosity value of castor oil is higher than that of base oils used in the formulation. As expected, while the viscosity indexes of formulations that contain canola oil as additive increases viscosity indexes of formulations that contain castor oil decreases slightly.

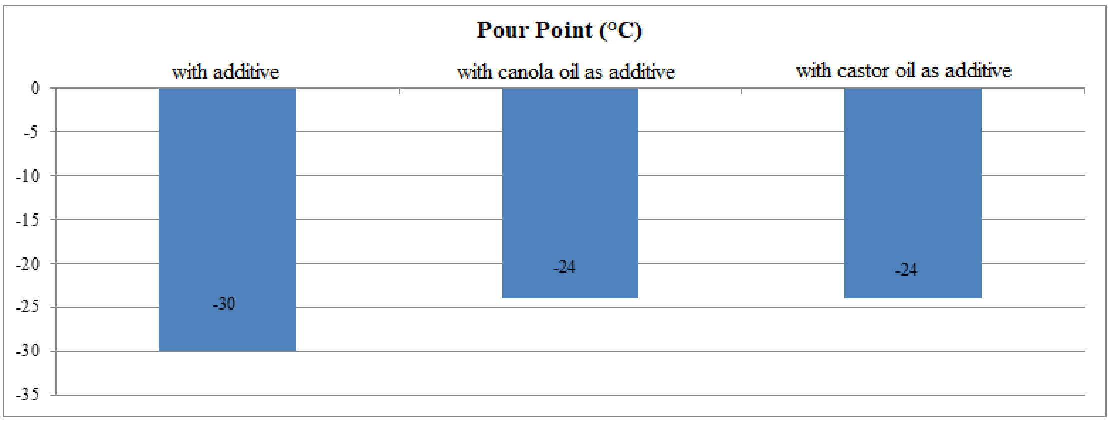
Density of canola and castor oils are higher than the density of mineral based oils used in the formulations. Therefore, as expected formulations that contain canola and castor oils as additives were found to have higher density values than those of reference lubricants. As can be seen in Figure 11 when castor is used as additive it increased the density more than canola since the density of castor oil is higher than that of others.

Figure 11. Density values



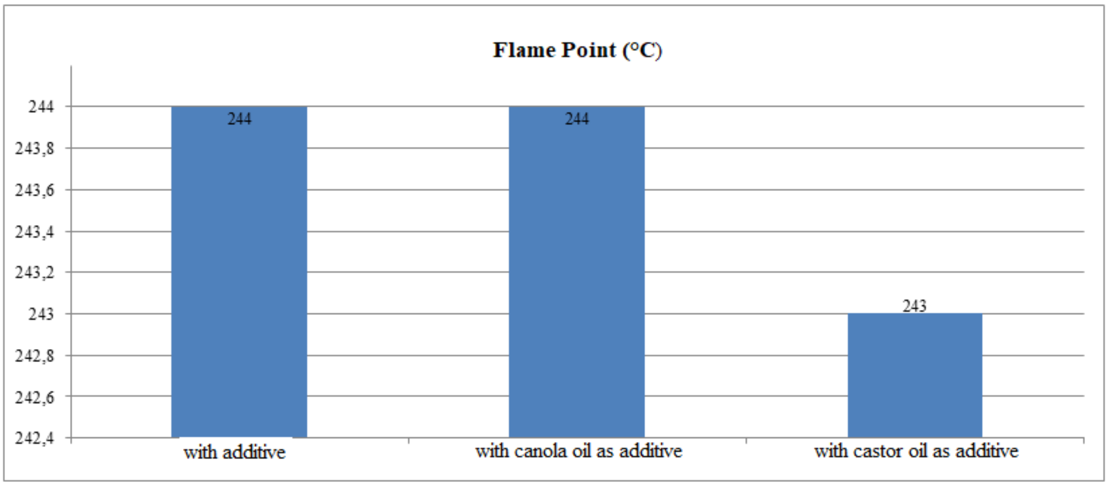
Pour point studies indicate that additives affect pour point. As can be seen in Figure 12 additive X in the hydraulic oil formulation functions as an agent that lowers pour point.

Figure 12. Pour point values



Since the pour points of heavy and light base oils are -24 °C. It can be calculated that additive X lowers pour point by 6 °C. As was observed using canola and castor oils as additives did not affect pour point.

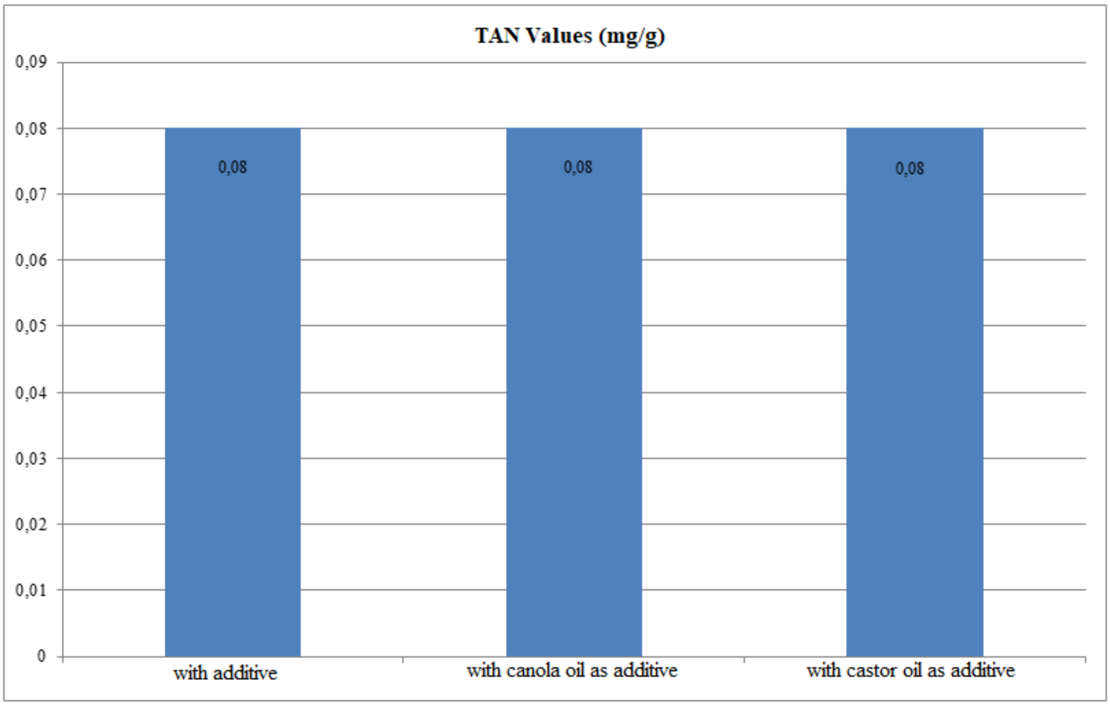
Figure 13. Flame point values



As shown in figure 4.13, an increase of 2° C at the point of exacerbation was observed when canola oil was used as an additive, and an increase of 1° C at the point of exacerbation was observed when castor oil was used. Based on this, it is predicted that the flaring point will rise even higher when the quantities of canola and castor oil are increased in formulations.

TAN and copper corrosion test results showed that since the amount of additives was very low the TAN values did not change considerably. This is can be seen in Figure 14.

Figure 14. TAN Values



4. Conclusions

The results obtained in the first part of the study indicate that vegetable oils have high flame point and their viscosities are less affected from temperature than mineral based oils and they have same pour points as mineral based oils. Corrosion test results for the mineral based oils and the vegetable based oils were the same. This indicates that vegetable based oils can be used as lubricants. However, the weakest property of vegetable oils is their oxidative stability. However, due to economic constraints oxidative stability studies could not be made. Since vegetable oils have favorable physical properties to be used as base oils in mineral oil formulations.

According to the results obtained in the second part although 4 g canola was used in the formulation at 40 and 100 °C it decreased the viscositiy values and in parallel to this increased the viscosity indixes. Moreover, it increased the flame point by 2 °C. This indicates that the additives can be used to improve these properties. Castor oil used as additive increased viscosity. In this respect, in cases when high viscosity is needed castor oil can be used. However, since it decreases viscosity index castor oil has a drawback too.

Extinguishing oil reserves and the ever increasing demand for power, energy and performance accompanied with increasing eco-consciousness and ever becoming more strict environmental laws and regulations brought about the necessity of providing alternatives to mineral based oils in the oil industry. It was observed that with respect to flame point, viscosity and viscosity index and pour point canola, soy, olive, corn, hazelnut and castor oils have favorable physical properties to be used as lubricant.

Since castor oil increases viscosity decreases viscosity index in the formulations it is used as additive its use as additive is restricted. However, canola oil was found to improve viscosity, viscosity index and flame point. Hence, canola oil can be a promising alternative for the additives used for improving these properties. When taken into consideration the cost and complex structure of the common inorganic additives vegetable oils would be attractive alternatives as the results obtained in this study show. Much effort still needs to be put in the quest for developing eco-friendly alternatives to mineral based oils.

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