# Tribological Properties of Untreated Vegetable Oils as Automotive Shock Absorber Fluids

Binfa Bongfa [1,2]*, S. Syahrullail [2], M.K. Abdul Hamid [2], P.M. Samin[2] and M. O. Adeoti[3]

[1]School of Engineering, Federal Polytechnic Idah, 271101 Idah, Kogi State, Nigeria
[2]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[3]Department of Mechanical Engineering, Federal Polytechnic Bida, 612101 Bida, Nigeria
*engrbinfabongfa@gmail.com

Abstract— *Automotive shock absorber fluids (ASAFs) serve in automotive hydraulic-type shock absorbers as damping fluids, lubricants, and coolants. Conventional ASAFs are petroleum-derived base oil(s) treated with additives, both of which are scarce, costly, and environmentally non-conforming. In this work, the tribological properties of atili oil, coconut oil, and groundnut oil were investigated on a Four-Ball Wear Tester (in accordance with ASTM D4172−94 method) as alternative basestocks for vehicle ASAFs. The vegetable oils, compared with a commercial petroleum-derived ASAF, showed superior friction reduction, and appreciable wear control. These results showcase these vegetable oils as suitable alternative basestocks for this application.*

Keyword— Vegetable Oils, Automotive Shock Absorber Fluids, Friction, Wear, Four-ball Wear Tester

## 1 INTRODUCTION

AUTOMOTIVE shock absorber fluids (ASAFs) are included in cylinders of automotive hydraulic-type shock absorbers to serve as damping fluids, lubricants, and coolants. ASAFs are manipulated by the shock absorber mechanisms to convert the energy of the spring, located on the suspension, to absorb heat and dissipate it to the surrounding [1]. Conventional ASAFs are composed of basestocks blended with additives. The basestocks as well as the additives used in formulating these fluids are petroleum-derived or synthetic. So far, scholarly publications revealed two crop oil-based ASAFs. One including only 37% blown rapeseed oil [2], and the second including monounsaturated fatty acids esterified with 2-alkyl-1-alkanol [3], a petrochemical and oleochemical industrial product [4]. The former still post relatively high environmental problem while the latter is expensive, and susceptable to corrosion and foaming. The prospect and possibilities of formulating ASAFs using vegetable oils (VOs), because of their promising physico-chemical properties and response to additives have been reviewed [5], but no work has established their suitability from tribological point of view.

While viscosity is a primary parametric requirement for suitable viscous damping in automotive shock absorbers, the ASAF is of utmost necessity required to reduce to an acceptable level, mechanical friction between contacting relative moving surfaces of the shock absorber components (in order to reduce the generation of heat and coulomb damping), and to control wear of the same. In this work, the performance of vegetable base oils in controlling mechanical friction, and wear of automotive shock absorber components have been investigated on a Four-ball Wear Tester in accordance with ASTM D4172− 94 test method.

## 2 MATRIALS AND METHODS

THE VOs used in this work are atili oil (ATO) (a specie of canarium schiveinfurthii), coconut oil (CNO), and groundnut oil (GNO) purchased from local markets within Nigeria. The benchmark fluid is a petroleum-based commercial shock absorber fluid obtained from a market in UK. SKF steel ball bearings of 12.7 mm diameter, 0.1μm C.L.A. surface roughness, 62 HRC Hardness, and chemical composition, 87.21% Fe, 10.2% C, 0.06% Ni, 1.46% Cr, 0.42% Mn, 0.07% S, 0.12% P, and 0.45% Si were obtained from a marketer in Malaysia.

The friction and wear tests were performed on a Four-Ball Wear Tester in accordance to ASTM D4172-94 test method (detail description is in [6]). After each test, the coefficient of friction (CoF) of the tribo-contact was extracted from the machine interface software on the computer and reported, while the wear scar diameters (WSDs) and the worn surface morphology were measured using a high resolution scale, (x100) and (x500) respectively, of an optical microscope. Two WSDs, one perpendicular and the other along the striations of each of the three lower balls were measured using the microscope and the average of the six readings recorded as the WSD (mm). The average surface roughness (Ra) of one of the three lower balls in each of the tests was determined using a surface roughness tester (stylus profiler-type).

## 3 RESULTS AND DISCUSSION

THE friction reduction performance of the nominated VOs, and the reference ASAF were expressed based on CoFs reported in Figure 1. The shorter the bar, the lower and more preferable the CoF. It can be seen from the chart (in Figure 1) that all the untreated vegetable oils (ATO, CNO, and GNO) have better friction reduction capacities than the reference fluid (COM), as seen between the tribo-contact of the balls. Among the vegetable oil samples, ATO has the lowest CoF (hence it is the best in-between-the-balls lubricant in terms of friction reduction) followed by (GNO, while CNO has the highest (being worst) CoF. The better performance by the vegetable oils in friction reduction is due to their amphiphilic nature, consisting of a long non-polar hydrocarbon chain (hydrophobic) and a polar head (hydrophylic), giving them strong positive effects on boundary lubrication [4]. The amphiphilic characteristics which is responsible for their high polar nature give them superior “oiliness”, and affinity to metal surfaces compared to the petroleum-derived oils [7].

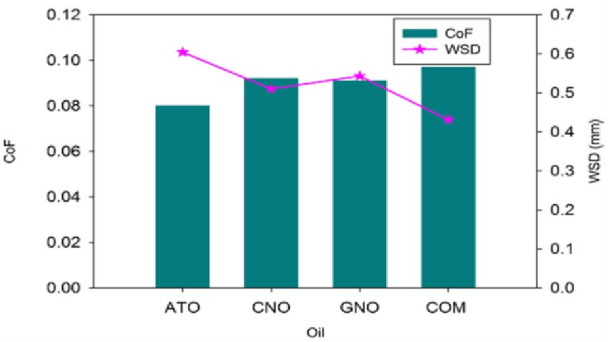


Figure 1: Plot of CoF and WSD of the tribo-contacts lubricated with the studied oils

This polar nature enables VOs absorb tenaciously with thin shearable films on metal surfaces, such that the oil molecules could sufficiently lubricate contacting faces of components designed with very low intervening spaces. The structure of arrangement of vegetable oil molecules in a tribo-contact zone is in such a manner that the highly reactive polar heads of the molecules get attached with strong orienting forces to the metal surface, while the long hydrocarbon ends stick away in a perpendicular array to the said surface [8]. The orientation enables these molecules to provide a slippery layer that hinders asperities-asperities contacts, and even when the arrayed layers are sheared off due to rubbing of the surfaces, they are quickly and simply recovered to their original estate by the strong orienting forces.

The behaviour of the CoF with time of the tested oil samples are presented in Figure 2. From the curves, the crop oils showed reducing CoFs with time, implying continuous increase of difficult-to-compress, but shearable films. ATO leads in this performance, followed by GNO. CNO is barely better than the COM in this performance. These abilities to produce stable and difficult-to-compress, but shearable thin-film attachments on interfaces of boundary lubricated tribopairs showed by the crop oils could give them recommendation as suitable ASAFs. Secondly, high reduction of friction between the relative moving contacting surfaces by these natural oils implies reduced heat generation owing to mechanical friction, compared to internal friction forces in the fluid. In such a situation, the metal elements may even extract heat generated by the fluid. This will contribute immensely to elongating the service life duration of the bio-based oils, and invariably the lubricated system, especially in non-refillable automotive shock absorbers where the life of the fluid is to a large extend the service-life of the unit. A well reduced mechanical friction in automotive shock absorbers also implies smoother ride quality. The superior performance of ATO in friction moderation connotes that the hydrogen-bonded polar matrix produced by the oil possesses superior resilience, and could much easily and quickly get restored unto the interfaces of the balls after being sheared by the load applied, compared to those of GNO and CNO. It is also traceable to the high stearic and palmitic content in its saturated fatty acids, and its long polar chains; the components reported to be very effective in friction reduction [4]. On the other hand, the high level of lauric and palmitic acid, and low unsaturated acids in CNO, coupled with its short chains can be the reasons for its poor friction modification ability. GNO, due to its moderate level of stearic and palmatic acids, and probably longer chain than those of CNO, but lower in both than ATO, occupied a mid-way performance in friction reduction.

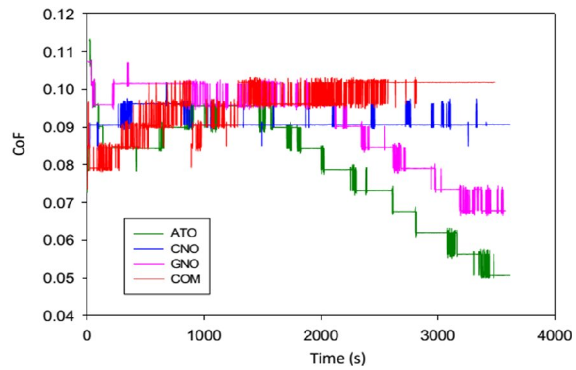


Figure 2. Variation of CoF of studied oils with time

Although the VOs have shown superiority over the commercial oil in lubricity, their capacity for retention of this property for a sufficient part of their service life in the desired application cannot be guaranteed. This is majorly due to the tribo-chemical transformation that do take place in them under severe service conditions, when temperature, metal surface, shear stress, pressure and service environment become applicable at the same time [4], and elevate the surface energy at the tribo-contacts. The rise in surface energy normally results in the desorption of the friction moderating molecules or films from the contacting faces of the tribocouple. If this occurs in an automotive shock absorber in service, it can give rise to asperities-asperities contacts at the cylinder-piston, rod-oil seal, and rod-rod guide interfaces, resulting in speedy increase of mechanical friction load. This friction can contribute to damping through coulomb effect, but to several disadvantages, including wear, poor ride quality, locking up of the suspension unit at small piston loads, and high heat generation which can cause thermo-oxidation of the fluid and even energy losses. Ideally, with crop oils as ASAFs, zero or negligible level of mechanical friction is desired, in order to reduce heat generation that can breakdown the oil, resulting in arbitrary change of the shock absorber’s designed damping parameters. This can be achieved through blending of the oil with the appropriate and potent boundary lubrication additives. Therefore, any of the tested VOs will need to be formulated with boundary lubrication additive(s), to meet the service duration required of ASAFs.

The curve in Figure 1 represents the average WSDs of the worn surfaces of the balls after the wear tests, using the studied oils as lubricants. It can be seen from the curve that ATO have the highest wear rate, followed by GNO, and then CNO. COM recorded an exceptionally low WSD, representing a good fortification against wear which may be due to the presence of antiwear additive(s). These results supported the argument of [9] which characterized the performance of boundary lubricating oils by surface phenomenon, including their chemical and physical absorbed layers and film formation on the substrates through chemical reaction. ATO and GNO might have produced weaker film bonding on the rubbing surface which were easily washed out under series of rubbing cycles and increased surface energy as temperature increased.

There is a reversal in the order of performance by the studied oils in terms of wear rate, when placed against their friction reduction. In general, the crop oils though recorded better friction reduction than the mineral oil, manifestly produced higher wear in the test. The scenario in this study confirmed the concept that crop oils could bring down significantly friction coefficient at metal-to-metal contact zones, however this may not necessarily imply that they would lower the rate of wear in the same manner. This is because the reduction of friction is effected by coating of contacting faces with slippery layers, while reduction of wear is by formation of tough coatings on the surfaces [7], which most crop oils may not be able to sufficiently generate. One other reason friction reduction ability of VOs does not guaranty their equivalent reduction in wear rate is that the two functions are dependent on their respective molecular structure. ATO, probably by forming superior slippery coating at the contact zones of the balls, reduced friction forces beyond GNO, and the later beyond CNO, but the toughness of their absorbed film could not resist wear activities as did CNO.

As observed with most native base oils [10], the fatty acids of these three VOs may have an enhanced reaction level, such that they react with the metallic soap layer formed during their tribo-interactions with the metal ball faces, and chemically convert the soaps to form lower shear-resistant compounds. While the resulting compounds should be slippery layers which reduced friction forces, they however, turn to expose the boundary lubricated faces of the balls to aggravate wear, being easily removable from the boundary lubrication zone. This behaviour is worst with ATO, followed by GNO, before CNO, as revealed in this particular test (Figure 1).

Next on the list of reasons behind the poor wear protection of the VOs is that the polar functionality in the triacylglycerol molecules have weaker surface absorption energy, hence they are easily washed off the tribo-contact zones of the balls as load and heat tower [7]. This allows direct rubbing of asperities to asperities, resulting in increased wear. The trend of this weakness of the surface absorption energy goes downward from CNO to GNO, then to ATO. Relatively, the lower unsaturated fatty acids and polarity in CNO reduce its actions against metallic films, while its dominant saturated fatty acids generate intermolecular bonding which adhere strongly to metal surfaces, giving rise to the formation of compact, thicker and shear-resistant polymeric matrix layers on the surfaces that reduce the wear rate. From Figures 1, the wide variations of CoFs and WSDs of the studied oils are sufficient to discriminate between the oil samples. This justified the selected test conditions.

The morphologies of the worn ball surfaces under the boundary lubrication of the test oils, captured using an optical microscope (X500) are shown in Figure 3. A close observation of the captured worn surfaces of the balls lubricated by the three crop base oils (Figure 3(a), (b), and (c)) showed severe wear than by the reference commercial fluid (Figure 3(d)). It can be seen in Figure 3(a) that the wear on the surfaces of ATO-lubricated balls is quite severe. This is evidenced by noticeable slight overspreading of metal layers, plowed surfaces, and deep grooves that are even so broad in some parts. The overspreading of metal layers is traceable to plastic deformation at the tips of asperities caused by rubbing of surfaces due to insufficient boundary lubricant at the contact zone. Secondly, high deficiency of oil film at the loaded interficial zones could cause bonding of asperity tips which result in shear within the material, as the bonded section become work hardened and very strong. The sheared material is transferred to the opposite surface giving rise to overspreading of metal at the surface. The plowed surface showed that sizeable particles have been removed from the surface. This must have occurred because of loss of oil film at the contact zones which allowed high build up of stresses there, resulting in local mechanical failure in which particles could coagulate and detach away as a single entity. This happens when environmental condition within the tribo-system reduces the surface energy to a level below the elastic energy at the contact areas, resulting in adhesive wear, which could be enhanced by cavitation and corrosion activities, and fatigue wear occasioned by repeated encounter of asperities. The implication of deep and furrows on the surfaces of the ATO-lubricated balls is that, apart from the insufficient surface protection by the oils, resulting in removal of particles at the interficial zone owing to adhesive wear, the initially removed particles became very aggressive abrasive substances which created deep grooves on the worn surfaces. The reality of the wear mechanisms being adhesive (since the oil and the ball cup were initially free of any particles), followed by abrasion, made manifest by the presence of pronounced serially linear grooves, flowing in the direction of rubbing of the rotating ball against the stationary ones. The deeper and broader grooves or higher peaks of the ridges in some part of the surfaces suggest clearly that some of the detached materials or debris which contributed in plowing the surfaces were of significantly large sizes. The surfaces of the balls lubricated by CNO and GNO (Figure 3(b) and 3(c) respectively) have similar nature with that of the ATO lubricated ball. The variation is that CNO produced smoother and less deep furrows than GNO while the latter produced similar dept but smoother furrows than those of ATO. These indicate that CNO formed relative better surface protection film matrix, followed by GNO, then ATO. The surface of the ball lubricated by the commercial oil (Figure 3(d)) have quite shallow, few, and smoother grooves when compared to any of the VOs, attestating to a higher level of surface protection. From the stand point of wear protection, the three VOs will require the support of antiwear additive(s), to serve as ASAFs.

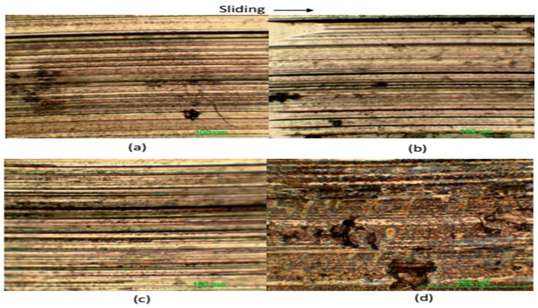


Figure 3. Morphology of the worn ball surfaces lubricated by the studied oils: (a) ATO; (b) CNO; (c) GNO; (d) COM.

Average surface roughness (Ra), averagely quantifies how the real worn surface at the end of the tribo-encounter has vertically deviated from the ideal surface before the encounter, hence, can be a suitable parameter for comparing lubricant performance. Table 1 shows the Ra values of one out of the three lower balls in the various tests performed using each of the studied oils.

Table 1: Worn ball Ra from each tested studied oil

| | Oil Sample | Ave. surface roughness, Ra (μm) |
|---|---|---|
| 1 | ATO | 0.287 |
| 2 | CNO | 0.032 |
| 3 | GNO | 0.382 |
| 4 | COM | 0.034 |

Among the vegetable oils, GNO shows the highest Ra, followed by ATO, and then CNO (Table 1), confirming in part the high degree of wear reported in Figure 1. This means that though the oil films of untreated ATO broke down easier than that of GNO, resulting in higher wear, smaller particle sizes were removed from the balls contact surfaces in ATO than in GNO. This can be deduced from the Ra values (Table 1) and the sizes of the grooves in the morphology in Figure 3(a) and (c). Oil films of CNO last longest and permitted removal of the smallest particle sizes among the base oils, as depicted by the Ra value in Table 1. One can deduce that the fatty acid chemistry of CNO, in collaboration with friction generated heat softens the removed particle, such that high contact pressures at the initially worn surfaces deformed them (particles) to the extent that their abrasive effects are minimized. The softening influence is lower with ATO. In GNO there appears to be heat-transformation hardening of the initial worn off particles resulting in creating deep grooves on the wearing surfaces of the balls by abrasive mechanism. COM, despite higher CoF than the VOs, still showed lower Ra. This indicates that Ra is more of the function of wear mechanism than of friction forces. The better wear prevention by the COM gives the lowest Ra. The Ra values of the VOs mean that they need to be treated with wear protection additives to meet the performance of the benchmark oil.

## CONCLUSION

THIS work has demonstrated that Atili oil (ATO), coconut oil (CNO), and groundnut oil (GNO) have superior friction reduction capabilities compared to a commercial petroleum-based automotive shock absorber fluid (COM). This is purportedly due to the amphiphilic characteristics (owing to high polar nature) of the VOs which give them superior "oiliness", and affinity to metal surfaces compared to the petroleum-derived oil. However, they have lower wear prevention abilities and created higher average surface roughness (Ra) compared to the commercial fluid. The VOs will require antiwear additive(s) to meet the performance of the commercial oil. With their (VOs) lower CoFs, they can appreciably reduce coulomb damping in automotive shock absorbers, especially when they are treated with friction modifier(s), giving room to dominantly viscous damping; thereby offering better ride quality, and lower heat generation.

## ACKNOWLEDGMENT

The authors wish to thank the Faculty of Mechanical Engineering, Universiti Teknologi, Malaysia. This work was supported in part by grants from Research Management Centre (RMC) UTM, RUG (02G34, 02G35, 09H64), and Ministry of Education Malaysia FRGS (4F610).

## REFERENCES

[1] N. B. Kate and T. A. Jadhav, "Mathematical modeling of an automobile damper," Int. J. Eng. Res., vol. 2, no. 7, pp. 467–471, 2013.

[2] D. L. Wright, "Shock absorber and similar mechanism." US Patent 2,236,662, 01-Apr-1941.

[3] D. Pirck and H.-D. Grasshoff, "Non-polluting shock absorber and level controller fluids." US Patent 5,474,714, 12-Dec-1995.

[4] J. C. Bart, E. Gucciardi, and S. Cavallaro, "Renewable feedstocks for lubricant production," Biolubricants Sci. Technol., pp. 121–248, 2013.

[5] B. Bongfa, S. Syahrullail, M. K. Abdul Hamid, and P. M. Samin, "Suitable additives for vegetable oil-based automotive shock absorber fluids: an overview," Lubr. Sci., vol. 28, no. 6, pp. 381–404, 2016.

[6] B. Bongfa, A. A. Peter, A. Barnabas, and M. O. Adeoti, "Comparison of lubricant properties of castor oil and commercial engine oil," J. Tribol., vol. 5, no. 1, pp. 1–11, 2015.

[7] B. N. Rhodes, "Vegetable Oil Based Internal Combustion Engine Oil," Chem. Ind. YORK-MARCEL DEKKER-, vol. 111, p. 557, 2006.

[8] A. Adhvaryu, S. Z. Erhan, and J. M. Perez, "Tribological studies of thermally and chemically modified vegetable oils for use as environmentally friendly lubricants," Wear, vol. 257, no. 3–4, pp. 359–367, 2004.

[9] W. Castro, J. M. Perez, S. Z. Erhan, and F. Caputo, "A study of the oxidation and wear properties of vegetable oils: soybean oil without additives," J. Am. Oil Chem. Soc., vol. 83, no. 1, pp. 47–52, 2006.

[10] L. I. Farfán-Cabrera, E. A. Gallardo-Hernández, M. Vite-Torres, and J. R. Laguna-Camacho, "Frictional Behavior of a Wet Clutch Using Blends of Automatic Transmission Fluid (ATF) and Biolubricant (Jatropha Oil) in a Pin-on-Disk Tester," Tribol. Trans., vol. 58, no. 5, pp. 941–946, 2015.