Viscosity Modifiers Versus Bearing Torque in Greases With Re-Refined Oil

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ABSTRACT

Re-refined base oils (RRBO) present a valuable opportunity for advancing sustainability in grease formulations, supporting a circular economy for lubricants. However, most re-refined oils are limited to ISO 15-46 viscosity grades, which are significantly lower than the ISO 220-460 grades typically required for grease applications. Viscosity modifiers can enhance RRBO to achieve higher viscosity grades, but their impact on grease rheology and load-carrying properties remains unclear.

This study builds on prior work where viscosity modifiers were used to successfully upgrade 25 cSt @ 40°C RRBO to ISO 220 base oil blends for NLGI HPM-HL multipurpose EP greases, showing performance comparable to control greases using Group I oils. This year's focus shifts to the application of polymer-enhanced RRBO in bearing greases, where proper viscosity and viscosity ratio (kappa) are critical for optimal performance. While industrial fluid specifications such as ASTM D6158 and AGMA 9005 have incorporated high viscosity index (VI) formulations, current grease standards are primarily based on VI 80-100 Group I oils.

In this study, the effects of increased VI and viscoelasticity introduced by viscosity modifiers were explored in sustainable bearing greases using RRBO at ISO 100. Viscosity modifiers, typically ranging from 10,000 to 200,000 g/mol, were compared with traditional synthetic base stocks like PAO and PIB, which have lower molecular weights. Bearing torque on 6204 deep groove ball bearings was measured and evaluated alongside apparent viscosity using a Brookfield CAP 2000 cone/plate viscometer. The goal was to understand the limits and impact of polymers on conventional bearing grease selection practices.

INTRODUCTION

It has been thought in the industry that the use of polymers in grease increases the “drag” or internal resistance of grease, especially in high tolerance mechanical systems with confined spaces like bearings. It is more common to find tackifiers, viscosity modifiers, or specialized grease polymers in heavy duty, wide tolerance equipment like oilfield or in other applications where the cohesion and adhesion of polymers helps to seal low tolerance equipment.

Sometimes viscoelastic effects can favorably manipulate the way grease moves on or through a test specimen to provide additional lubrication at the site of wear. This has been observed in studies of tacky greases in bearing life tests and MTM where the viscoelastic response of tackified grease pulled displaced grease from a bearing race or path of the MTM ball back into the site of wear to continue providing protection[2], [3].

This study builds on several years of research presented annually at conferences to address notions about the limitations of polymers of all types in building viscosity, water repellency, oil retention, tack, and adhesion in greases. Bearing greases have resisted using higher molecular weight additives, but may make use of polybutene (polymers of isobutene and its isomers) or polyalphaolefins (highly branched polymers of various alpha olefins like decene, dodecene, and more).

Greases made using low viscosity re-refined oils are an ideal test bed to explore the interactions of polymers. Re-refined base oils (RRBO) are increasingly popular due to the need to reduce the carbon footprint of petroleum-based lubricants on the scale and economics required by the industry now[4]. The efficiency of bearings is now more than ever an area of key interest from OEMs and bearing manufacturers due to energy inefficiency in bearings being a greater cause for emissions than bearing or lube production[5].

EXPERIMENTAL

Lab-Scale Grease Production

Greases were prepared from pre-formed thickener using a small, 1-kg scale open kettle design in a Hobart C-100 mixer with an electric heating mantle operating at 400-450°C regulated by a temperature controller (BriskHeat SDC120KC-A) with K-type thermocouple.

Pre-formed lithium 12-hydroxystearate powder (HX-1 grade), base oil, and antioxidant were charged to the kettle at room temperature and allowed to heat for 30 – 45 minutes until the powder dissolved at 190 - 220°C and formed a clear solution. This target temperature varies based on base oil solvency or aniline point. The heating mantle was then removed and the grease batch was continuously stirred until cooled to 80°C.

The crude grease was transferred to a EXAKT 50 three-roll mill and homogenized in two passes before pumping through a 150 micron mesh to remove any aggregates.

Milled grease was allowed to rest for 24 hours before measuring grease consistency. Greases were then adjusted as needed by heating to 60°C, adding more base oil, and mixing in the Hobart mixer for 30 minutes.

Consistency Testing

Consistency of greases was measured by ASTM D1403, quarter cone penetration. It was important to allow the greases 24 hours to stabilize their consistency before measuring and adjusting.

Addition of Polymers to Grease

Greases with viscosity modifier were prepared by heating a base grease to 60°C and adding the liquid viscosity modifier. The grease was mixed for 30 minutes in a Hobart mixer to ensure even distribution of the additive.

If a formulator wants to prepare a specific ISO viscosity grade for a fluid from a low viscosity base oil then the formulator must first determine the treat rate (wt%) of viscosity modifier to use. This is done by preparing at least three different treat rates and preparing a plot of treat rate versus viscosity. The desired wt% viscosity modifier can be estimated graphically or by solving more accurately with a regression.

If viscosity modifier is added to a base grease consisting of oil and thickener then the formulator must compensate for the wt% thickener content to produce the correct ratio of base oil to viscosity modifier.To determine how much viscosity modifier to add when top treating grease, first identify the wt% viscosity modifier in the pure base oil to obtain the desired viscosity grade (i.e. ISO 100). For example, start with the case that it was determined that 12wt% of a specific viscosity modifier in the base fluid is required to meet an ISO 100 viscosity grade and the base grease contains 7wt% lithium soap..

Following this equation, the correct mass of viscosity modifier to add (in grams) per 100 grams of base grease is:

$$\frac{grams\ viscosity\ modifier}{100\ gram\ of\ base\ grease} = \frac{100 \times (1 - \%\boldsymbol{T})\ \times\ \%\boldsymbol{VM}}{1 - \%\boldsymbol{VM}}$$

where,

%T = wt% thickener in base grease

%VM = desired wt% viscosity modifier in pure base oil for ISO VG target

Given 7 wt% thickener and a desired 12 wt% viscosity modifier in the base oil, the formulator should add 12.68 grams of the viscosity modifier per 100 grams of grease. This will yield a final 12 wt% viscosity modifier in the ‘oil phase’ of the grease (total mass of oil plus viscosity modifier) and a final wt% thickener of 6.21 wt% by dilution.

Add the mass of solid additives (graphite, molybdenum disulfide, etc.) to the wt% thickener and add the mass of liquid additives (packages, ZDDP, antioxidant, etc.) to the mass of the base oil for the purpose of calculation.

Apparent Viscosity by Brookfield

Apparent viscosity in Pascal was measured via cone-and-plate geometry on a Brookfield CAP2000L viscometer from 50 – 1600 rpm at 20, 40, and 60°C. #01, #02, and #03 cones were used. Time per run was set to 30 seconds. This process is modified from ASTM D4287.

Temperature was set to the target temperature and allowed 15 minutes to stabilize with the cone in the down position on the heated platform. The cone was then raised and approximately two grams of grease were transferred to the center of the platform. The cone was lowered slowly to allow the grease to spread out evenly from under the cone. The excess material extruded from out under the cone was wiped away using a Kimex wipe. The grease was allowed to equilibrate to the set temperature for 5 minutes.

The grease was first run-in for 30 seconds at 50 rpm. Any material expelled during the run-in was again wiped away from the cone with the tip of a gloved finger.

Once run in, the same grease sample was run for 30 seconds at 50, 100, 200, 400, 800, and 1600 rpm in sequence with 10 seconds between runs to enter the new test speed on the instrument. The values for each rpm were recorded. If the test becomes out of range for the instrument given the speed and viscosity of the sample (reports “EEEEP” or blinking “P”) then the run is marked as “N/A” and no higher rpms are tested.

At 40 and 60°C, the #02 cone was used for all the greases except the low viscosity (ISO < 46) greases where a #01 cone was used. The instrument cone setting is set to the number of the cone.

At 20°C, it was necessary to use the #03 cone but set the instrument to the #02 cone setting to obtain the proper range of apparent viscosities for the grease at 20°C. The viscosity with this #03 cone / #02 setting was multiplied by a XXX correction factor. Low viscosity greases (ISO < 46) used the #03 cones and the #03 setting on the instrument.

Kinematic Viscosity and VI

Kinematic viscosities were measured manually in capillary tube viscometers by ASTM D445. Viscosity index was calculated by ASTM D2270. Operating viscosities at arbitrary temperatures were calculated by using the viscosity at 40°C, viscosity at 100°C, and the ASTM D341 method for extrapolating viscosity to different temperatures.

Preparing the 6204 Bearings

The 6204 bearings for testing were bought as Timken 6204-2RS shielded deep groove ball bearings. The shields were carefully removed and the bearings were submerged in mineral spirits at 60°C overnight to soften the grease. The grease was then brushed out with a small nylon brush before soaking again in mineral spirits overnight. After rinsing, the degreased bearings were stored under mineral spirits.

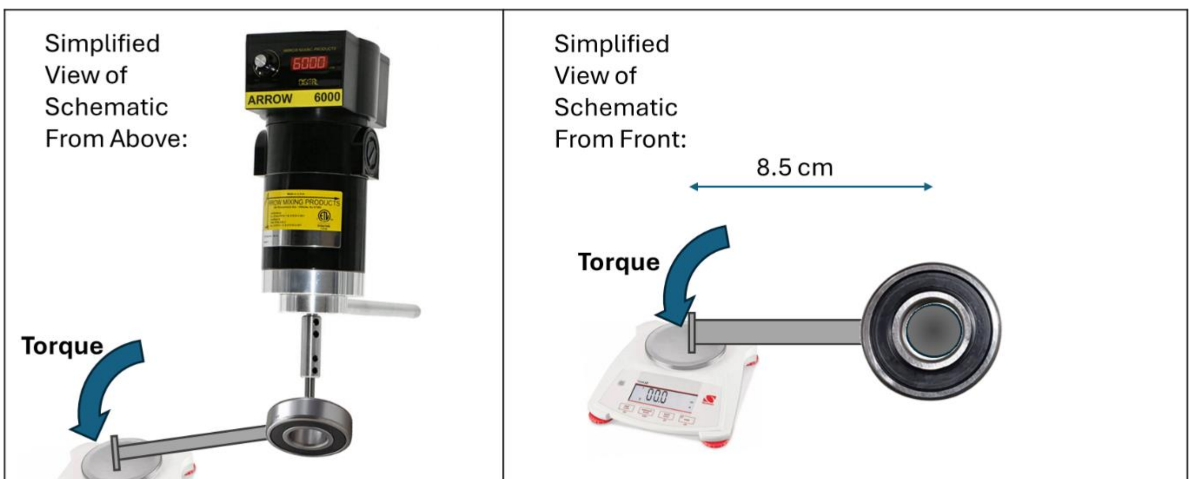
Free volume of the empty bearings was estimated at 8.9 mL with shields and 12.0 mL without shields.

Before testing, the empty 6204 bearings were rinsed twice with isopropyl alcohol and dried with filtered air to remove trace solvent.

A 5 mL syringe was packed with approximately 5 mL of grease to determine an approximate density for each grease sample. Bearings were packed with 3.5 mL of grease from a syringe with small beads (~0.25 mL) applied to each side of the cage with 1.75 mL on each side. This achieves a 40% fill rate after closing the shields within the rule of thumb of 33 – 50%.

Bearing Torque Test

The torque transmitted through a bearing due to the internal resistance of the grease in a bearing was measured by a simple lever arm style instrument. **Figure 1** highlights the key features.



$$Torque, mN \cdot m = (Grams\ on\ Scale) \times 8.5cm \times \frac{0.0980mN \cdot m}{g \cdot cm}$$

Figure 1: A very simple schematic of the bearing test rig showing the key linkages between motor and the lab scale (acting as load cell); and a depiction of the torque measurement.

An expanding arbor is inserted into the inner diameter of the bearing and expanded to clamp the bearing from within. The arbor is attached to a shaft which is spun by an Arrowing Engineering Model 6000 Digital electric motor with a digital readout of the exact motor speed from 50 to 6000 rpm.

The outer diameter of the 6204 bearing is secured by a 1 ½" diameter clamp which connects to a 61.5 mm long metal rod. The opposite end of the metal rod is supported by a laboratory scale. The overall length of the lever arm, from the inner diameter of the bearing to the tip of the lever, is 85 mm. At rest the weight of the lever arm on the load cell measured 85.4.

In a perfect bearing, there is no internal resistance or friction and no torque is transmitted through the rotating inner race to the outer race which is kept from rotating by the lever. No load would be registered on the laboratory scale. In the worst bearing (i.e. a coupling), all of the torque from the motor is transmitted through the inner race to the outer race and the outer race / level must rotate or the motor stalls. This would transmit a very high load to the laboratory scale or even break some connection between the motor and lever. In reality, some fraction of the rotation of the electric motor will pass through the inner race to the outer race via internal resistance and friction of the bearing and grease. A load of 15 – 30 grams was observed in this study depending on the grease and conditions. This equates to a torque of 12.5 – 25 mN-m given the effective lever length of 8.5 cm.

Torque was measured as the downward force applied to a laboratory scale through a 85 mm lever arm from the center of the bearing to the end of the rod. The resting torque of the lever arm weight without rotation of the bearing was 71.2 mN-m. This may be considered a static radial load as well as the centrifugal forces of the bearing elements in rotation.

To prepare the test, the scale was zeroed to measure the net force of the torque exerted by the outer race of the 6204 bearing. The entire side of the bearing with shields was scanned with an IR thermometer and the highest temperature observed was reported as the initial temperature.

To run the test, the motor was set to 100 rpm and the force on the lab scale was recorded within five seconds. After five minutes at 100 rpm, the force on the lab scale was recorded again and the bearing surface was scanned by IR thermometer with the highest observed temperature recorded. The motor speed was increased to 200 rpm, the new load on the lab scale recorded within 5 seconds, and the motor was allowed to run for 5 minutes again. This process repeats for 300, 400, 500, 600, 700, and 800 rpm.

Several values are calculated to evaluate the greased bearing:

- **Torque**, in mN-m, from the load on the laboratory scale based on the equation in the figure above
- **% change in torque**, as the percent change in torque from the first torque measured at 100 rpm

- **dT**, as the difference in temperature at the time of measurement minus the initial temperature
- **Operating viscosity** of the base oil in the grease based on 100 cSt @ 40C, the viscosity index, and the measured temperature of the bearing
- **Viscosity ratio**, or kappa, the operating viscosity divided by the ideal viscosity in **Table A**

Table A: Ideal viscosities of the 6204 bearing reported by the online SKF Bearing Select Tool [6]

Rpm	100	200	300	400	500	600	700	800
Ideal Viscosity (cSt)	152	83.5	58.7	45.7	37.6	32.1	28.1	25.0

Ambient temperature in the laboratory was 22.5°C.

<u>Base Oils and Blends</u>

This study included several popular high viscosity base oil categories to show the effects of 'conventional' base oil blends versus the low viscosity re-refined base oil built up with viscosity modifier. Comparing multiple ISO 100 base oil blends establishes a range of typical behavior since solvency and molecular weight of the base fluid can impart different rheology to grease.

Table B and **Table C** list the base oils and blends used to prepare ISO 100 base oil blends for grease making. **Table D** shows the properties of the RRBO.

Table B: Individual base oils selected from various API Groups

Base Oils for Control Greases	**API Group**
200 SUS Naphthenic Oil	V
750 SUS Naphthenic Oil	V
150 SUS Hydrotreated Group I	I
Hydrotreated Group I Bright Stock	I
220 SUS Group II Oil (6 cSt @ 100°C)	II
600 SUS Group II Oil (12 cSt @ 100°C)	II
PAO 6 (6 cSt @ 100°C)	IV
mPAO 100 (100 cSt @ 100°C)	IV
5 cSt Group II+ Re-Refined Base Oil	II

Table C: ISO 100 base oil blends from mixing dumb bell blending a light and heavy cut.

ISO 100 Blend Name	VI	Combination
ISO 100 Naphthenic Blend	26	70% 750 SUS Naphthenic Oil + 30% 200 SUS Naphthenic Oil
ISO 100 Group I Blend	100	52% Group I Bright Stock + 48% 150 SUS Hydrotreated Group I
ISO 100 Group II Blend	97	91% 600 SUS Group II Oil + 9% 220 SUS Group II Oil
ISO 100 Group II/Naphthenic Blend	81	65% "ISO 100 Group II Blend" + 35% "ISO 100 Naphthenic Blend"
ISO 100 PAO Blend	162	62% PAO 6 + 38% mPAO 100

Table D: Base oil properties for the re-refined base oil (RRBO) to modify with polymer.

Base Oils for Polymer Modified Greases	VI	KV @ 40C	KV @ 100C
5 cSt Group II+ Re-Refined Base Oil	117	28.5	5.25

Grease Formulas

Base greases using Group I, Group II, naphthenic, or PAO base fluids were formulated as a set of control groups to benchmark against polymer modified greases based on low viscosity re-refined base oils (RRBO). The control greases including PAO grease were made using dumb bell blends of a light cut and a heavy cut, with both cuts charged to the kettle during the initial soap formation. Including the heavy cut, especially for the mPAO in the PAO based control grease, may have negatively affected the yield due to the use of pre-formed thickener.

Only base fluid, thickener, antioxidant, and viscosity modifier were added to the grease. This was intended to allow any tribological effects of low viscosity ratios (kappa $\leq$ 1) on the bearing to be observed as potential spikes in torque.

Tables E and **F** outline the basic formula of the conventional oil based and experimental polymer-modified greases.

Table E: Control grease composition

Component	Weight Fraction
Pre-formed Lithium 12-Hydroxystearate (HX-1 grade)	6 – 15wt%
Base Oil	84 – 93wt%
Antioxidant (Phenolic/Aminic Blend)	1wt%

Table F: Finished polymer-modified grease composition

Component	Weight Fraction
Pre-formed Lithium 12-Hydroxystearate (HX-1 grade)	6 – 15wt%
Viscosity Modifier (includes active polymer and diluent oil)	5 – 30wt%
Base Oil	54 –88 wt%
Antioxidant (Phenolic/Aminic Blend)	1wt%

<u>Viscosity Modifiers</u>

A wide range of viscosity modifiers were chosen based on varying chemistry and molecular weight to probe the relationship between viscosity from polymer, the resulting VI of the oil phase, the resulting apparent viscosity and rheology of the grease, and the bearing torque of the grease in a real bearing. **Table G** compares basic physical properties and chemical identity of the nine VMs studied.

Table G: Properties of viscosity modifiers used to build the viscosity of the RRBO to ISO 100.

Name	Pure Form	Chemistry	Shear Stability*
50 SSI OCP	Bale	Olefin Copolymer, Diluted in Oil	50 SSI by K-O
33 SSI OCP	Bale	Olefin Copolymer, Diluted in Oil	33 SSI by K-O
22 SSI OCP	Bale	Olefin Copolymer, Diluted in Oil	22 SSI by K-O
7 SSI Styrene OCP	Flake	Styrene Olefin Copolymer, Diluted in Oil	7 SSI by K-O
Polymethacrylate Base Stock	Liquid	Polymethacrylate, Small Dilution with Oil	15 SSI by KRL
Ethylene-Propylene Oligomer	Liquid	Ethylene-Propylene Copolymer, low MW	12 SSI by KRL
mPAO 300	Liquid	Metallocene Polyalphaolefin	<10 SSI by KRL
PIB 2300	Liquid	Polyisobutylene	<10 SSI by KRL
Low Temp Polyolefin	Liquid	Polyolefin – Proprietary	4 SSI by KRL

* by “K-O” refers to ASTM D6278; by KRL” refers to CEC L-45-A-99 or 20 hour tapered roller bearing test

Finished Control and Experimental Greases

Properties of the control greases (grease without viscoelastic effects from polymer) are shown in **Table H** and experimental greases (grease with viscoelastic effect from polymer) in **Table I**. "Tack Type" refers to the tackiness behavior previously described in a previous study[7]. Tack type was presented in a previous work as a rating from 1 to 4 which describes increasingly viscoelastic and non-Newtonian behavior with increasing value. The kinematic viscosity (KV) at 40C shown in the table below and used for calculation were normalized to 100 cSt. All greases were used in the apparent viscosity study but only two control greases and two experimental greases were evaluated in the bearing torque test.

Table H: Properties of Control Greases with ISO 100 Petroleum Blends

Control Greases (no VM)	**Tack Type**	**wt% Thickener**	**Cone Pen.**	**Grade**	**KV @ 40C**	**KV @ 100C**	**Viscosity Index**
Naphthenic Blend	4	6.8%	268	2	100	8.5	26
Group I Blend	2	12.0%	305	1.5	100	11.4	100
Group II Blend	3	14.6%	287	2	100	11.2	97
Group II / Naph. Blend	2	12.0%	279	2	100	10.3	81
PAO Blend	3	17.0%	287	2	100	15.3	162
Re-Refined Base Oil (5 cSt)	2	15.0%	262	2.5	28.5	5.3	117

Table I: Properties of Experimental Greases using RRBO with Viscosity Modifier

Experimental Greases (RRBO + VM)	**Tack Type**	**wt% Thickener**	**Cone Pre.**	**Grade**	**KV @ 40C**	**KV @ 100C**	**Viscosity Index**	**wt% VM in Oil**
Ethylene Propylene Oligomer	2	13.20%	275	2	100	13.7	138	13.2%
33 SSI OCP liquid VM	3	12.90%	283	2	100	16.0	172	16.0%
50 SSI OCP liquid VM	4	13.20%	288	2	100	15.9	171	14.0%
Low Temperature Polyolefin	2	13.60%	290	2	100	19.2	216	10.0%
22 SSI OCP liquid VM	4	12.80%	300	1.5	100	16.1	173	17.0%
7 SSI styrene OCP	3	12.40%	302	1.5	100	16.6	181	20.0%
Polyisobutylene	2	12.40%	305	1.5	100	13.5	135	20.0%
mPAO 300	2	11.80%	324	**1**	100	16.6	181	24.0%
Polymethacrylate Base Stock	3	11.30%	341	**0.5**	100	15.6	167	25.2%

RESULTS AND DISCUSSION

Preliminary Bearing Torque Test

Development of a simple bearing torque test was desired to investigate the effects of basic grease formulation strategies on the rheology of grease. The current setup operates from 100 to 800 rpm and relies on frictional heating of the bearing to passively heat the bearing. Very simple experiments can often yield direct and useful results of physical properties in grease[8].

The temperature and force measurements at various rpm creates a multi-dimensional array of data that can be used to compare conventional and polymer modified greases. In the future, heating and cooling of the unit will be necessary to probe viscosity ratios < 1 or >4.

This preliminary study was limited to two control and two experimental greases to determine the range of behavior to be expected in the novel bearing test and determine if the speeds and ISO VG have been appropriately selected.

Figure 2 below shows the temperature-time profile for the conventional "Group I" (ISO 100 with VI 100) and "Group II / Naphthenic" (ISO 100 with VI 82) based simple lithium greases compared to that of experimental greases using RRBO built to ISO 100 with viscosity modifier. Two very different viscosity modifiers were chosen: the high molecular weight, dilute, and tacky "50 SSI OCP" (ISO 100 with VI 171); and the shear stable, concentrated, and highly fluid chemistry of the "Low Temperature Polyolefin" (ISO 100 with VI 216).

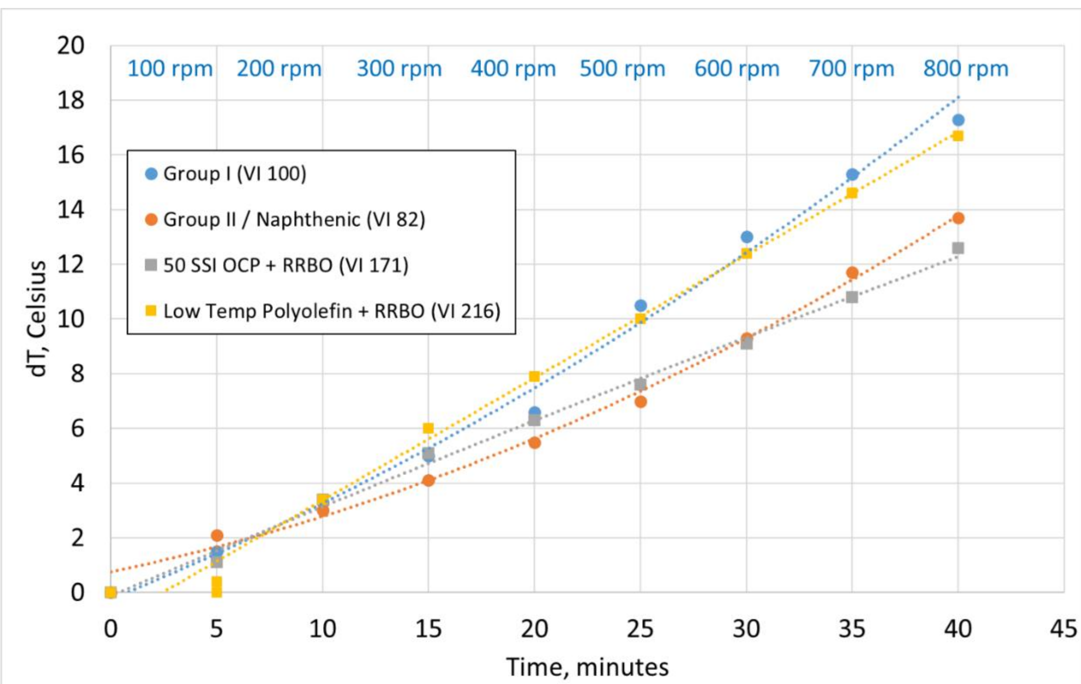


Figure 2: Profile of temperature rise from starting temperature (dT vs. time) of two conventional greases using conventional ISO 100 petroleum oil blendsgreases versus greases formulated using ISO 100 blends of RRBO with two very different viscosity modifiers.

Temperature rise was due to both friction between moving surfaces and heat imparted by the work to push the grease around the well-packed bearing. The reported temperatures are only surface temperatures on the outside of the bearing and it is expected that the internal temperature will be many degrees higher under the plastic shield which insulates heat. Five minutes was sufficient for the measured torque to stabilize but may not have been long enough to stabilize the temperature as a function of rpm. Future method development will focus on how long these test stages should be.

The conventional Group I oil and Low Temperature Polyolefin greases produced similar heating rates with a total gain of +17°C in 40 minutes. The Group II / Naphthenic greases were also closely paired with similar rates of temperature increase to +12-13°C in 40 minutes.

Interestingly, the greases with the lowest temperature gain in the experiment were the greases with the highest and lowest viscosity indexes. Polymer modified greases were comparable and slightly below the conventional greases in thermal behavior.

Figure 3 compares the measured bearing torque after each 5 minute / 100 rpm increment. This plot shows at the end of the 800 rpm stage that the Low Temperature Polyolefin grease with very high VI (VI 216) produced the highest bearing torque of 25.4 mN-m, the Group I grease (VI 100) followed at 21.4 mN-m, then the lower VI Group I / Naphthenic Oil (VI 82) grease at 19.3 mN-m, and the 50 SSI OCP at 16.8 mN-m. This trend closely follows the same trend as **Figure 2** which showed the heating profile over time.

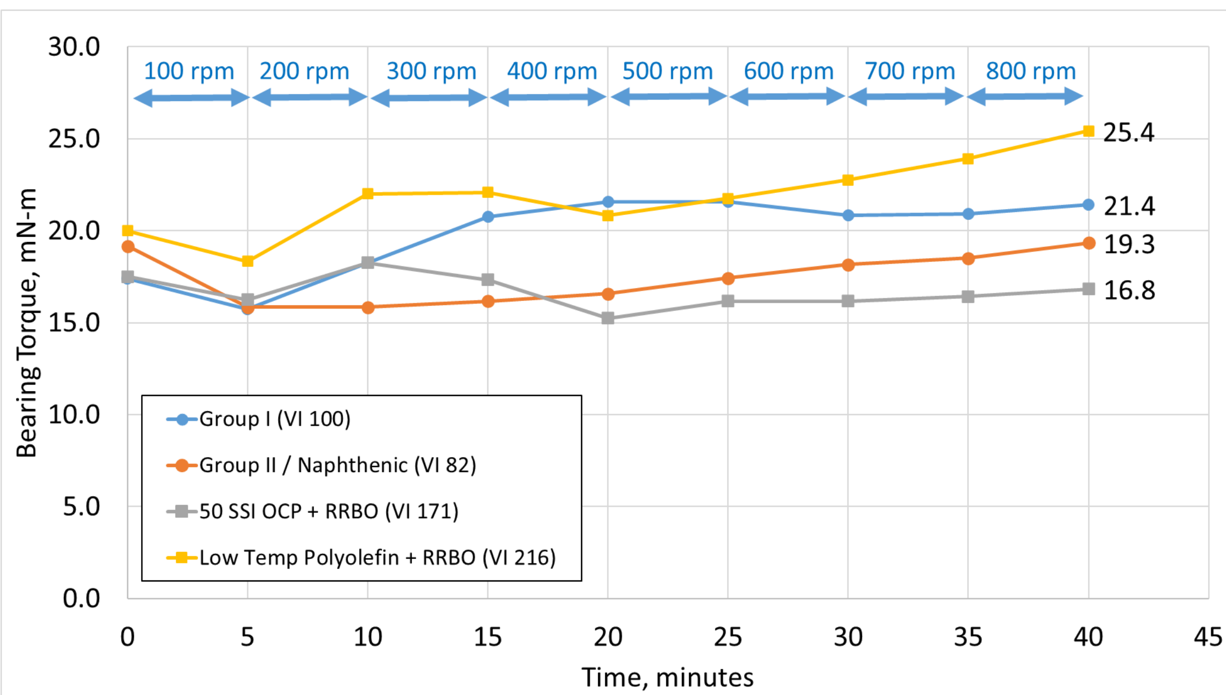


Figure 3: Bearing torque at the end of each speed stage over time.

Polymer modified greases exhibited the highest and lowest torque from the sample set after the 100-800 rpm ramp. An initial drop in torque between 0 – 5 minutes may be a result of the initial working of the grease and temporary breakdown of lithium fiber structures.

Given the difference in viscosity index, the base oil from each grease will thin at different rates as they heat. Another consideration is that for the 50 SSI OCP there is also a sensitivity to temporary shear thinning at high speeds as the polymer coil orients with the direction of motion and provides less viscosity. This could explain why the 50 SSI OCP polymer modified grease initially follows the Group I grease profile up to 200 rpm but torque begins to lower after $\geq$ 300 rpm while the other greases exhibit increasing torque. Last year's study estimated a high molecular weight polymer like the 50 SSI OCP could temporarily lose up to 50% of its viscosity by 900 rpm in a Brookfield CAP 1000 experiment[1].

The viscosity index from viscosity modifiers may produce higher than desired viscosities at elevated temperatures compared to VI 80 – 100 in a conventional petroleum oil. The remedy is to reformulate the Low Temperature Polyolefin grease at a lower ISO VG but same operating viscosity at expected temperatures.

Possible shear thinning behavior in the 50 SSI OCP case may also highlight that higher molecular weight viscosity modifiers can beneficially compensate for the effect of high VI by thinning under high rpm.

The results from the preliminary study on the simple bearing torque test rig are encouraging. Further work is needed to make the system rigid enough to accommodate rpm > 800 and heat or cool the bearing to explore the effects of operating viscosity effects. The bearings in this study were lightly loaded and results may vary due to tribology occurring at lower rpm and viscosity ratios under heavy load.

Ultimately, the bearing torque test rig measures the output of a complex interaction of viscosity, the thickness of the grease, and the rotation of the bearing. There were obvious differences in the toughness of greases formulated to the same consistency ranges which necessitated a follow-up study on the apparent viscosity and shear thinning behavior of the conventional and polymer modified grease.

Apparent Viscosity by Brookfield

Apparent viscosity in grease is equivalent to dynamic viscosity in fluids. Dynamic viscosity is the resistance to flow under an active shearing force like a spindle (rather than kinematic viscosity which is the resistance to flow under a fluid's own gravity). If a material is Newtonian then the viscosity remains constant whether the speed of shearing increases or decreases. If a materials is non-Newtonian, like grease, then the viscosity tends to decrease as the speed of shearing increases. Some non-Newtonian materials will "shear thicken" and increase in viscosity as the speed of shearing increases.

While oil is the majority of the grease composition, the thickener and polymer-thickener interaction is also key to understanding the performance. Many of the grease formulations exhibited different rheology with varying levels of tack or ease of mixing with a spatula though they were NLGI #2 with ISO 100 oil.

Greases have complex and time dependent relationships between shearing and their consistency both during and after manipulation of the grease[9]. A variety of greases with the same NLGI grade by cone penetration can also exhibit greatly different resistance to manual stirring which calls into question the utility of cone penetration[10]. Capturing the effects of formulation changes on the behavior of grease calls for study at multiple speeds and temperatures, rather than just NLGI grade, in order have an idea of how it will affect torque in use.

The apparent viscosity of control greases and experimental greases was obtained from Brookfield cone and plate viscosity measurements from 50 – 1600 rpm at 20C. As rpm increases, viscosity decreases rapidly but an exponential or logarithmic regression did not fit the data . The best fit was from plotting rpm on the x-axis and (viscosity in cP)^-2 in the y-axis. Then a nearly linear plot was produced from which a slope could be fit. This slope was multiplied by 10^4 to give an easy to handle value around 0 – 1.

The slope described above is considered to be a measure of grease "softness." Lower values meaning the grease is 'softer', i.e. more resistant to shear thinning, and more Newtonian. Greases with higher values of softness will rapidly lose more viscosity while under shear and behave more non-Newtonian. Softer greases should be easier to pump and generate lower churning losses than tougher greases.

Table J ranks the control and experimental greases by order of softness. Control greases and experimental greases using pure liquid polymer in higher concentrations all rank < 0.7 softness. Viscosity modifiers with higher molecular weight demonstrate higher softness up to 2x to almost 4x the softness. The RRBO base grease without viscosity modifier had a 4.44 softness value.

Table J: Control and polymer-modified experimental greases listed in order of softness. "Softness" is the slope of rpm vs. viscosity^-2, multiplied by 10^-4 as described above. Greases highlighted in orange were featured in the bearing torque test. Higher Softness denotes faster drop in apparent viscosity with shear rate.

Grease Sample	Softness Rating
PAO Control	0.164
Group II Control	0.324
RRBO + Polyisobutylene	0.472
Group II/ Naphthenic Control	0.486
RRBO + PMA Base Stock	0.514
RRBO + Ethylene-Propylene Oligomer	0.552
Naphthenic Control	0.587
RRBO + Low Temperature Polyolefin	0.616
RRBO + mPAO	0.646
Group I Control	0.654
RRBO + 7 SSI Styrene OCP	1.307
RRBO + 50 SSI OCP	1.847
RRBO + 22 SSI OCP	2.198
RRBO + 33 SSI OCP	2.292

Multiple factors in tandem likely determine bearing torque of the grease. Further work is needed to create a bigger data set using the approach developed in this work and determine which factors have the strongest correlation to the torque and temperature rises observed.

CONCLUSIONS

Re-refined base oils (RRBO) offer a sustainable solution for grease formulations without the need for a complete overhaul of the industry's reliance on petroleum-based stocks. While alternative biobased or biodegradable basestocks could provide greater sustainability, they would require a fundamental shift in grease formulation, selection, and economics. RRBO represents a practical compromise, balancing sustainability with established industry practices.

The main challenge with RRBO lies in its limited viscosity grades, typically capped at ISO 46, due to the low viscosity of reclaimed oils. To achieve higher viscosity grades necessary for many grease applications, viscosity modifiers (VMs) must be employed. However, the effects of using polymers to build viscosity, rather than heavy petroleum oils, are not yet fully understood. Gaining this knowledge is essential for widespread adoption of RRBO in the grease industry.

Viscosity modifiers introduce additional complexity in grease formulation, affecting not only the viscosity index (VI) but also cohesion, adhesion, and viscoelastic properties like shear thinning.

The bearing torque tests conducted in this study demonstrate that greases formulated with two different viscosity modifier chemistries performed comparably to conventional Group I/II/naphthenic oil blends in both torque and temperature rise in 6204 deep groove ball bearings.

The results suggest that higher molecular weight polymers, through shear thinning, can reduce bearing torque, making the "softness" of the grease—its resistance to shear thinning—more critical than the viscosity index increase from the added polymers. This softness metric could be used as a predictive tool in future studies to identify greases that will generate less resistance in bearings and other mechanical components during operation, paving the way for more efficient and sustainable grease formulations using RRBO.

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