Organic friction modifiers

Perfad™ 3000, Perfad 3006 and Perfad 3050 for engine oils

Perfad 3000, Perfad 3006 and Perfad 3050 polymeric organic friction modifiers for engine oils

We have developed a new range of organic friction modifiers based on polymer chemistry, Perfad 3000, Perfad 3006 and Perfad 3050.

Perfad 3000, Perfad 3006 and Perfad 3050 reduce the coefficient of friction of engine oils to levels unachievable with conventional organic friction modifiers, enabling formulators to develop engine oils that improve fuel economy and reduce emissions. Perfad 3000, Perfad 3006 and Perfad 3050 also demonstrate excellent film forming properties, offering the potential to reduce engine wear and to improve engine durability.

Technical performance benefits

- Extremely low coefficient of friction in boundary and mixed lubrication regimes for low and elevated operating temperatures on steel-on-steel contacts
- Outstanding friction reducing properties on diamond-like carbon (DLC) coated surfaces
- Increased fuel economy in challenging engine tests
- Protected surfaces and minimised wear by building durable lubricant films under boundary conditions
- Little or no harmful effects in many industry standard tests
- Based only on C, H and O: they do not contain sulphated ash, phosphorus or sulphur (SAPS)
- Increased oxidative stability compared to traditional organic friction modifiers providing improved in-service operation and longer life
- Effective at low dose rates, typically 0.5 - 1.0%

Typical physical properties

Properties	Perfad 3000	Perfad 3006	Perfad 3050*	Perfad 3057
Physical form	Viscous liquid	Viscous liquid	Viscous liquid	Viscous liquid
Colour	Dark brown	Dark brown	Dark brown	Amber
Dynamic viscosity at 40°C (mPa.s)	10640	6400	114000	2540
Dynamic viscosity at 60°C (mPa.s)	2730	2000	23300	2040
Dynamic viscosity at 80°C (mPa.s)	990	800	6690	660
Dynamic viscosity at 100°C (mPa.s)	440	360	2700	225
Iodine value (gI/100g)	25	1.1	6.5	4.7
Acid value (mgKOH/g)	7.5	1.2	4	1.2
Density at 20°C (g/ml)	0.97	0.98	0.97	0.97
Flash point (°C)	270	269	280	280
Pour point (°C)	>21	4	>21	3
SAPS (% w/w)	zero	zero	zero	zero

Table 1 Typical physical properties of Perfad 3000, Perfad 3006, Perfad 3050 and Perfad 3057

*Perfad 3050 is not available as a 100% active product but is supplied as a 70% active product (Perfad 3057) for ease of handling

Outstanding friction reducing properties

Mechanical movements in engines include contacts which are both 'sliding and rolling' and 'pure sliding'. Frictional characteristics of Perfad 3000, Perfad 3006 and Perfad 3050 are exemplified later in the brochure using a selection of laboratory bench tests.

Steel-on-steel contacts - sliding/rolling friction

In its standard setup the Mini Traction Machine (MTM), shown in Figure 1, allows the precise measurement of friction by loading a steel ball against a steel disc using highly controlled parameters.

Commercially available engine oils (Table 2) have been top-treated with Perfad 3000, Perfad 3006 and Perfad 3050 and tested at 60 and 135°C using the test conditions shown in Table 3. Comparative testing was conducted against a conventional organic friction modifier: glycerol monooleate (GMO).

Engine Oil	Viscosity grade	Specification
EU oil (Europe)	5W-30	ACEA A3/B3, A3/B4, C3
JP oil (Japan)	5W-20	API SN, GF-5
NAM Oil (North America)	5W-20	API SN, ACEA A1, GF-5

Table 2 Engine oil specifications

In order to determine the film forming and frictional characteristics of friction modifiers, it is important to run tests on virgin surfaces and also on surfaces which are conditioned through opposing surface contact. Our testing protocol includes a rubbing profile which involves bringing the ball and a smooth disc into contact at slow speeds for a period of 120 minutes. This rubbing profile allows the development of anti-wear films, which may not be formed when running an initial Stribeck curve and which lead to higher frictional contacts between opposing surfaces. Test conditions for the rubbing profile can be seen in Table 4.

Figure 1 Mini Traction Machine with magnified steel ball against steel disc configuration

Polymeric friction modifiers provide low friction performance in typical European, Japanese, North American, Indian, Brazilian and Chinese engine oils

Parameter	Value
Applied load	36 N (1.01 GPa)
Lubricant temperature	60 and 135°C
Slide/roll ratio	0.5
Entrainment speed	0.005 – 3.5 m/s
Disc material	AISI 52100
Disc surface finish	< 0.01 µm Ra
Disc hardness	720 – 780 HV
Ball material	AISI 52100
Ball surface finish	< 0.02 µm Ra
Ball hardness	800 – 920 HV

Table 3 MTM Stribeck curve conditions

Parameter	Value
Applied load	30 N
Lubricant temperature	60 and 135°C
Slide/roll ratio	0.5
Entrainment speed	0.05 m/s

Table 4 MTM rubbing conditions

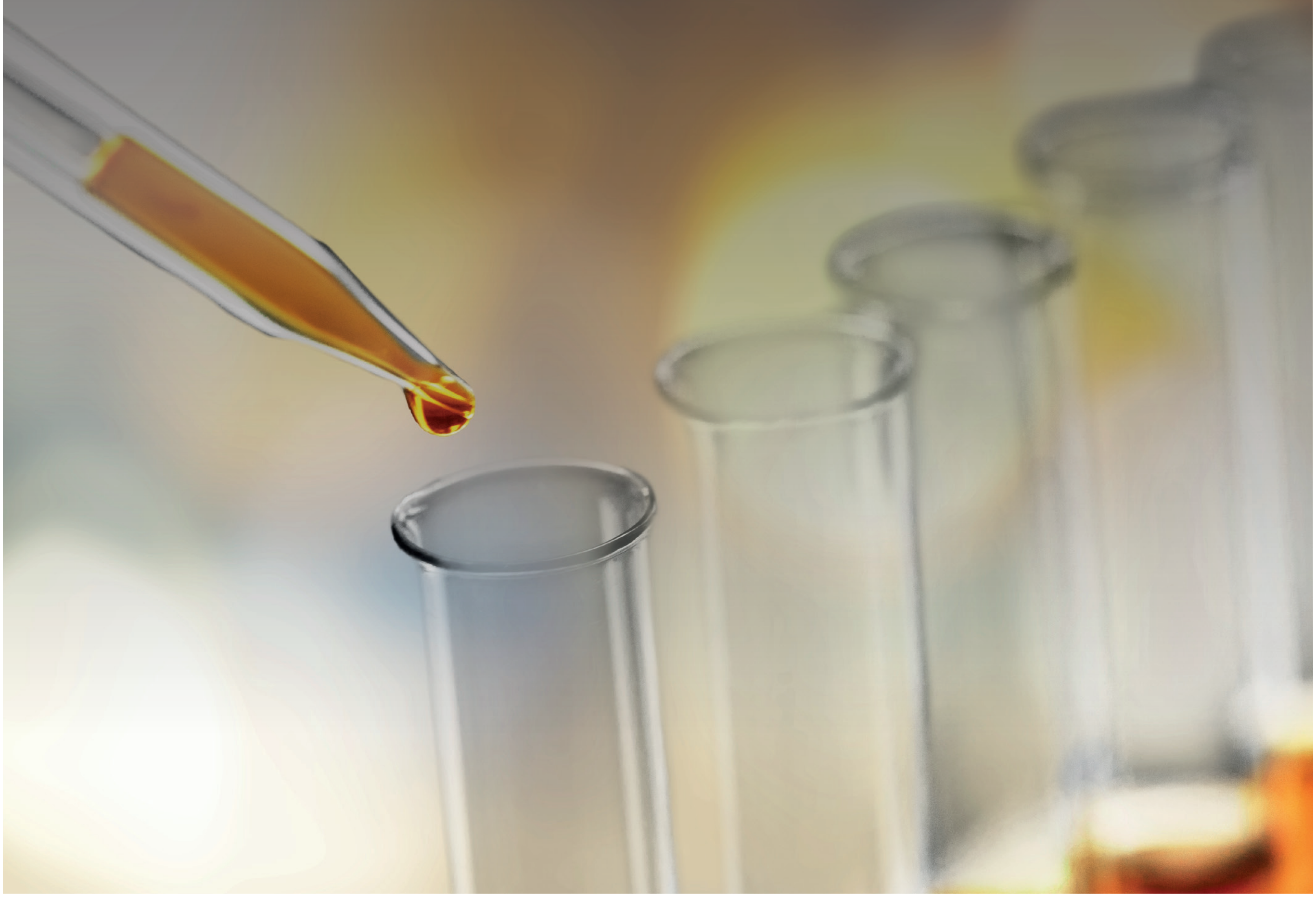
High performance at low operating temperatures

Oil sump temperatures of 90 – 110°C are considered normal for vehicles which are used for a minimum of 20 minutes, but many journeys are typically short in duration and therefore engines spend a significant amount of time operating under high stress conditions where the bulk oil temperature may not reach the ideal sump temperature. With the introduction of stop-start technology, the continuing growth in hybrid vehicles and the increasing use of low viscosity engine oils, it is ever more important that friction modifiers can provide low friction at low operating temperatures.

Polymeric friction modifiers deliver between 20 and 55% reduction in friction in mixed sliding/rolling contacts at 60°C

Figures 2, 4 and 6 demonstrate how Perfad 3000, Perfad 3006 and Perfad 3050 can immediately provide extremely low friction to engine oils with a bulk oil temperature of 60°C, and in practice at lower temperatures still.

Figures 3, 5 and 7 demonstrate how Perfad 3000, Perfad 3006 and Perfad 3050 continue to provide very low friction compared to the untreated engine oils and engine oils top-treated with GMO, even after two hours of rubbing.



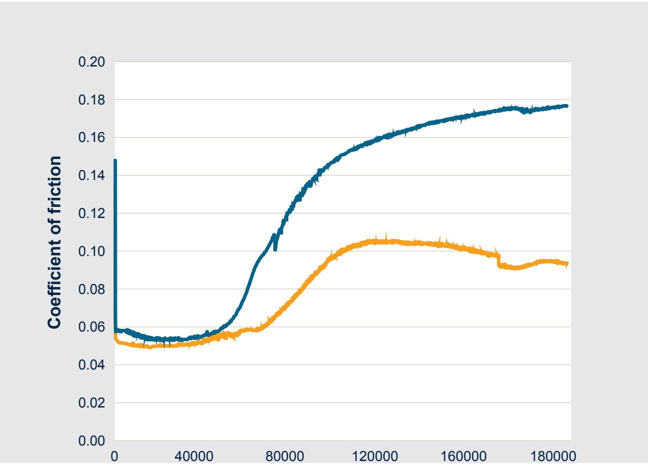


Figure 2 MTM results for European engine oil + friction modifiers at 60°C - 0 mins

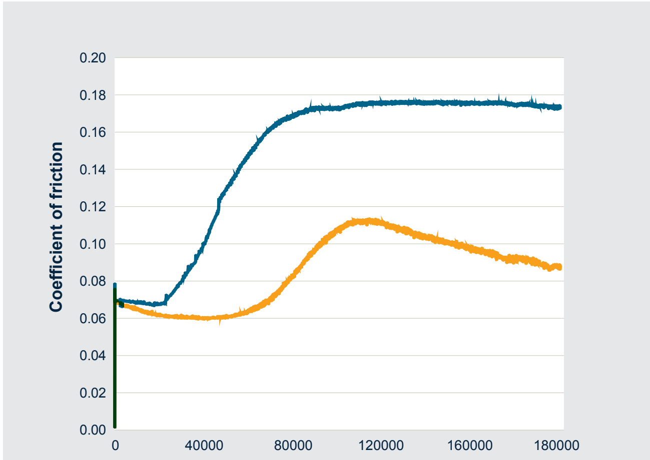


Figure 3 MTM results for European engine oil + friction modifiers at 60°C - 120 mins

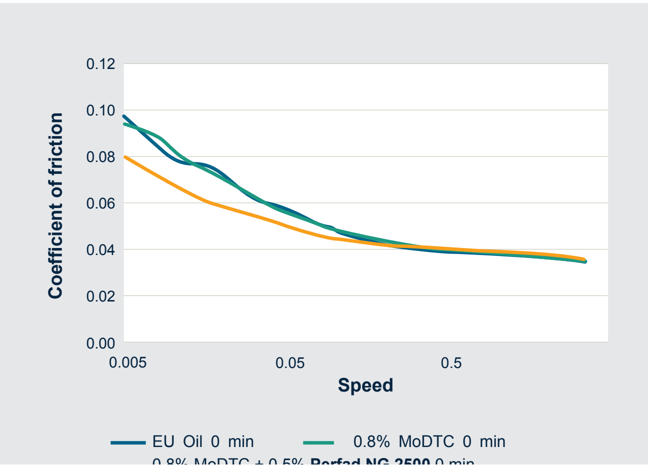


Figure 4 MTM results for Japanese engine oil + friction modifiers at 60°C - 0 mins

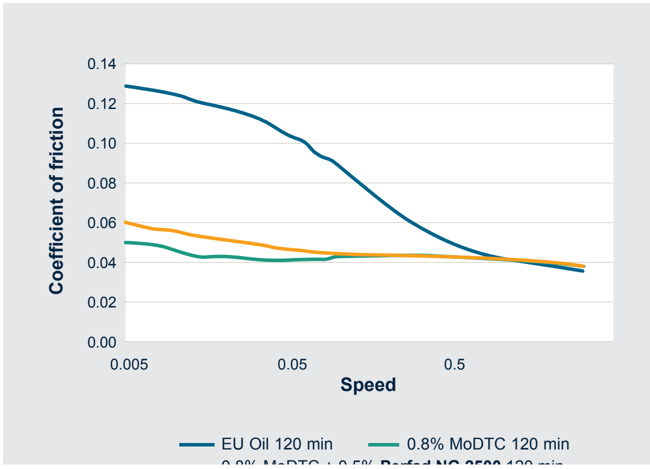


Figure 5 MTM results for Japanese engine oil + friction modifiers at 60°C - 120 mins

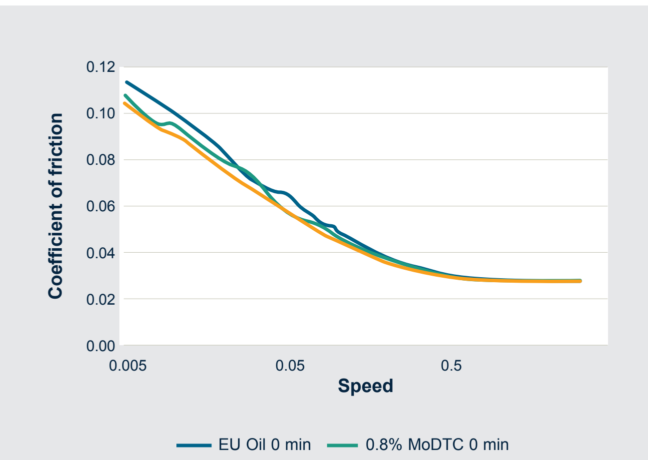


Figure 6 MTM results for North American engine oil + friction modifiers at 60°C - 0 mins

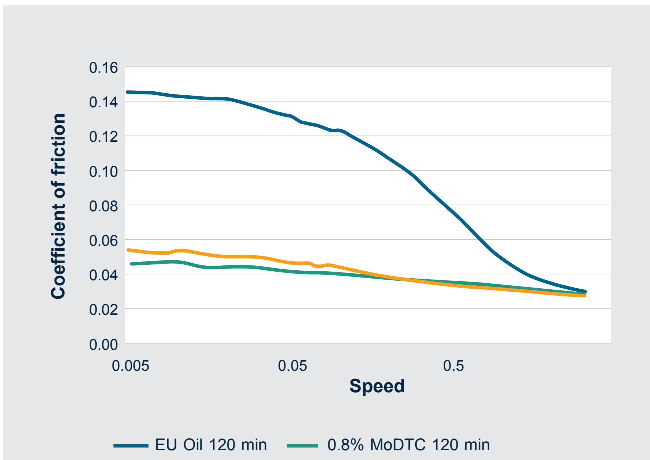


Figure 7 MTM results for North American engine oil + friction modifiers at 60°C - 120 mins

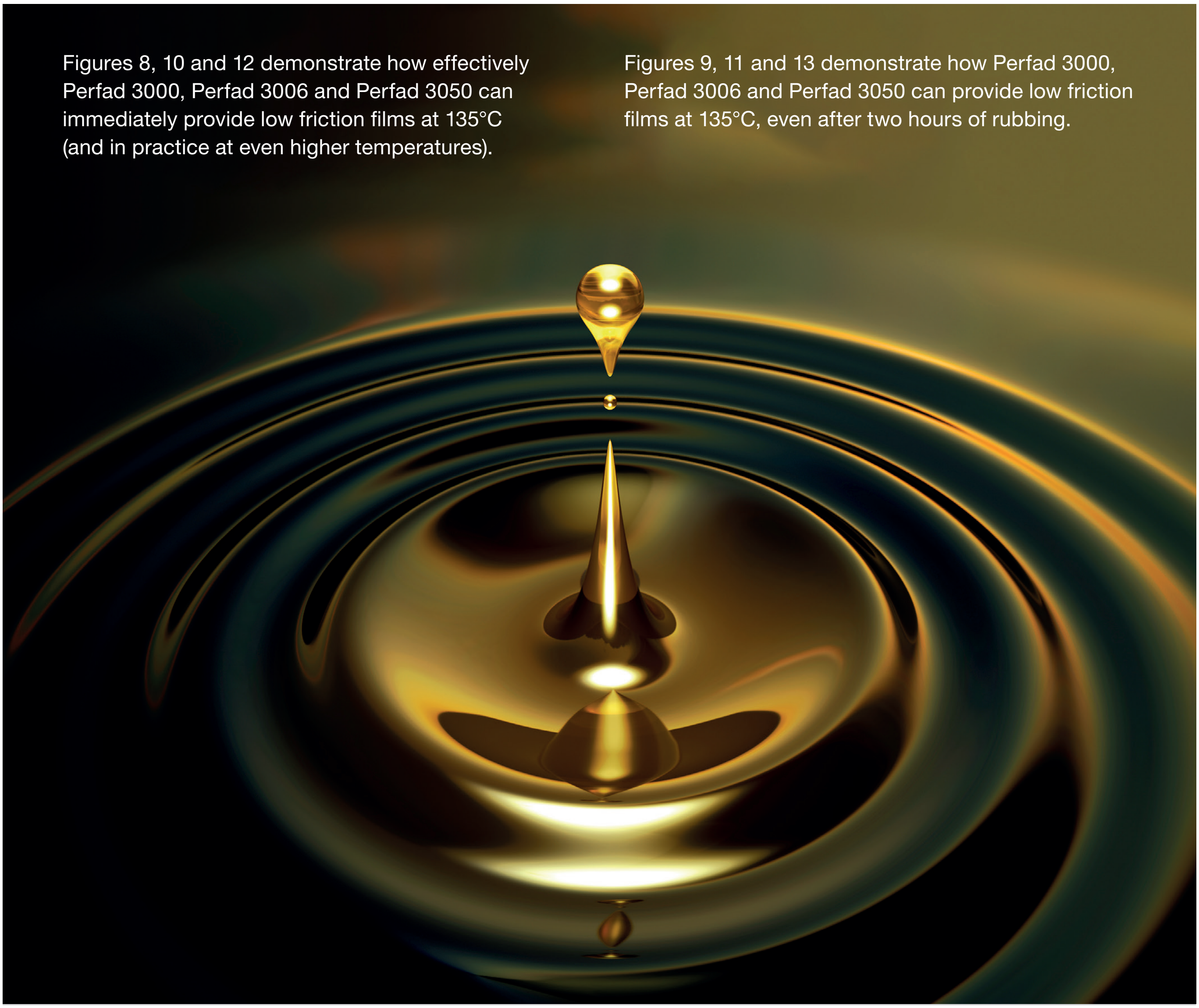
High performance at elevated operating temperatures

At higher temperatures the oil viscosity decreases and the film forming properties of the engine oil also decrease. At these temperatures, the engine will spend more time in boundary and mixed lubrication conditions (compare Figure 2 and 8), therefore it becomes even more important to use film forming additives to ensure that adequate protection is provided between the opposing surfaces. This can be achieved by correctly selecting one or more friction modifiers, such as Perfad 3000, Perfad 3006 and Perfad 3050 or through the use of anti-wear additives.

Our polymeric friction modifiers deliver between 20 and 90% reduction in friction in mixed sliding/ rolling contacts at 135°C

Figures 8, 10 and 12 demonstrate how effectively Perfad 3000, Perfad 3006 and Perfad 3050 can immediately provide low friction films at 135°C (and in practice at even higher temperatures).

Figures 9, 11 and 13 demonstrate how Perfad 3000, Perfad 3006 and Perfad 3050 can provide low friction films at 135°C, even after two hours of rubbing.



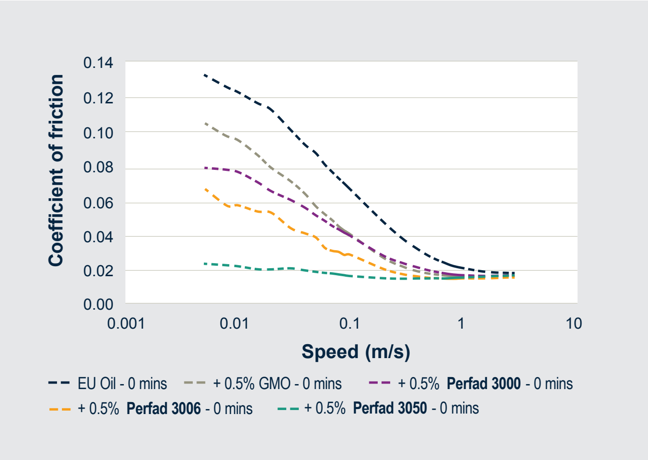


Figure 8 MTM results for European engine oil + friction modifiers at 135°C - 0 mins

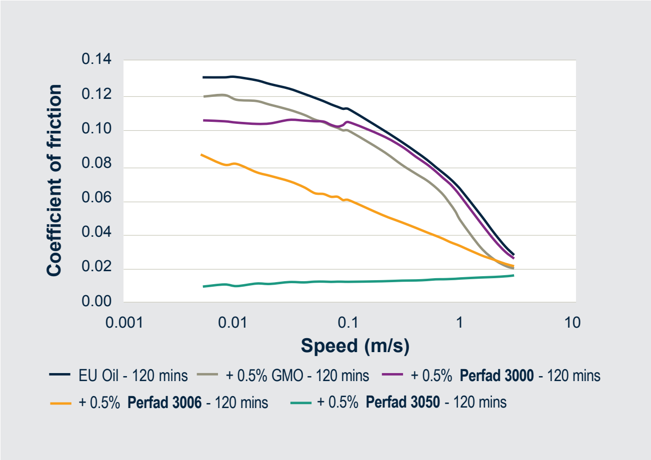


Figure 9 MTM results for European engine oil + friction modifiers at 135°C - 120 mins

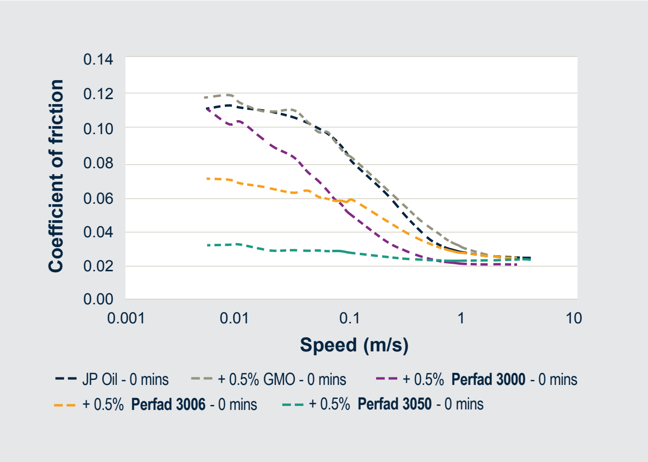


Figure 10 MTM results for Japanese engine oil + friction modifiers at 135°C - 0 mins

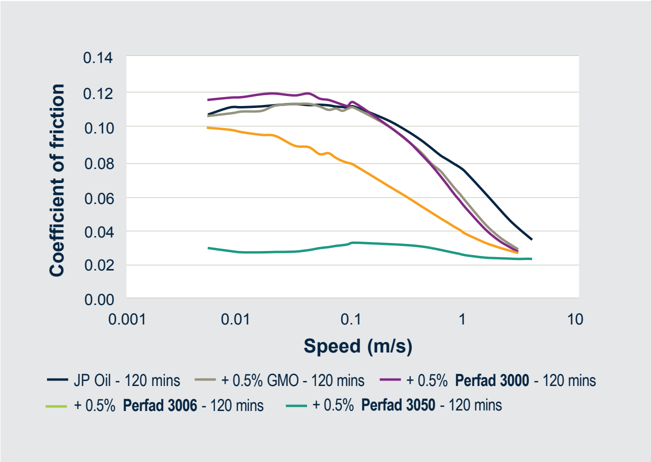


Figure 11 MTM results for Japanese engine oil + friction modifiers at 135°C - 120 mins

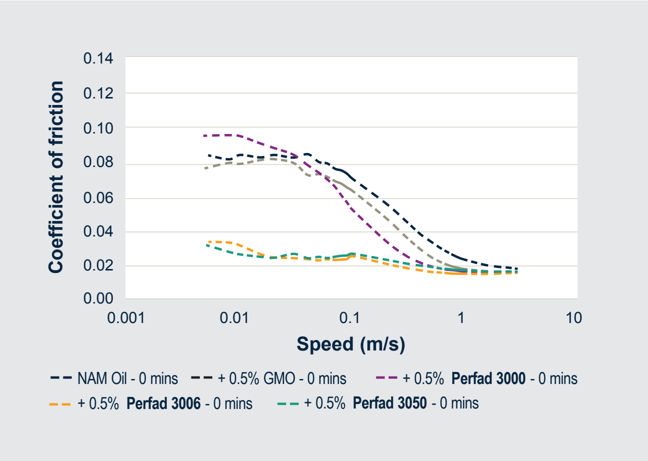


Figure 12 MTM results for North American engine oil + friction modifiers at 135°C - 0 mins

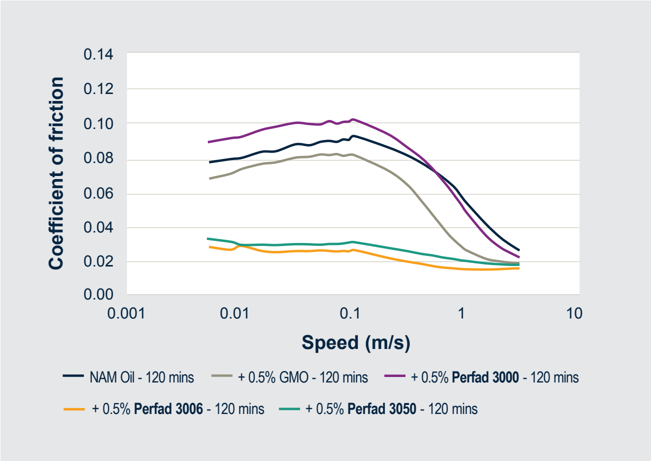


Figure 13 MTM results for North American engine oil + friction modifiers at 135°C - 120 mins

Longerlife oils/lower SAPS engine oils

Engine oils, when lubricating virgin metal surfaces, form polyphosphate films when thermally or mechanically activated. Friction modifiers (polymeric, conventional organic and inorganic) are typically more surface active than zinc dialkyl dithiophosphate (ZDDP) and all immediately form a protective low friction layer, as demonstrated in the Stribeck curves previously. Rather than preventing the formation of a polyphosphate film, friction modifiers slow the film formation whilst still providing low friction and anti-wear performance (Figure 14). The darker images below indicate the increasing thickness of the polyphosphate film which develops over time.

The use of polymeric friction modifiers delays the formation of the polyphosphate film the longest and may enable the formulator to develop longerlife fluids, or could allow for a similar lifetime but at reduced SAPS levels.

Polymeric friction modifiers are able to reduce friction between components that have only been previously lubricated by a polymeric friction modifier free engine oil

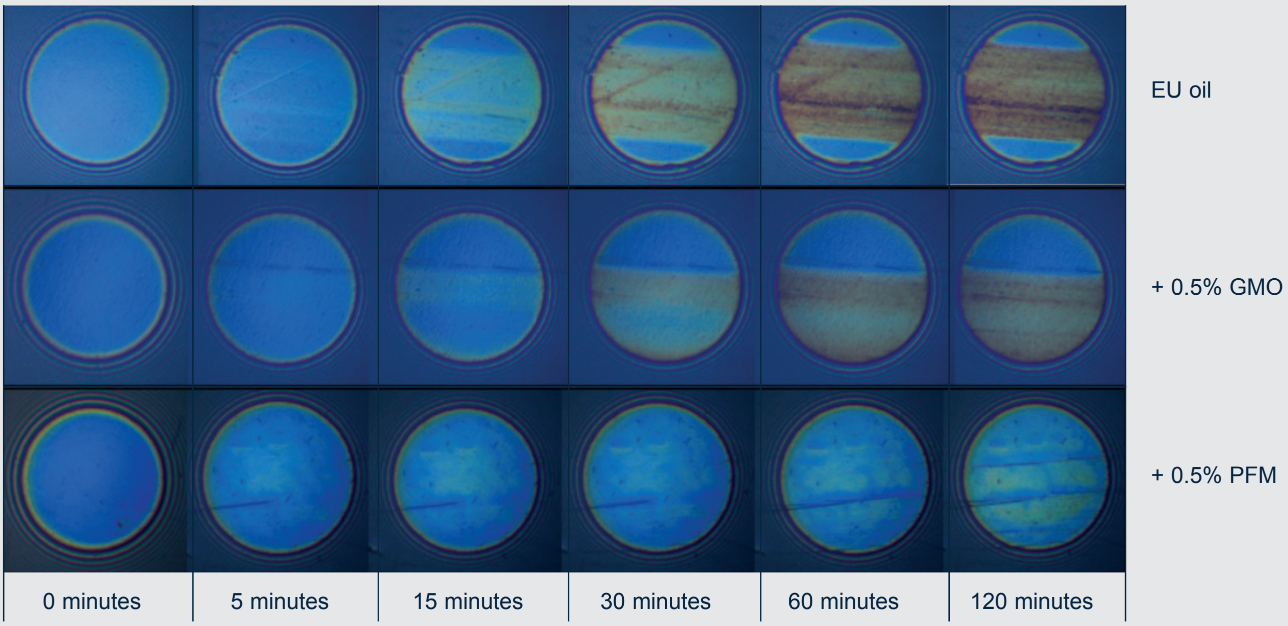


Figure 14 Interference images of European engine oil + friction modifier with increased rubbing time

After 120 minutes of rubbing a friction reduction of 75% is observed with polymeric friction modifiers compared to the friction observed for the European oil alone

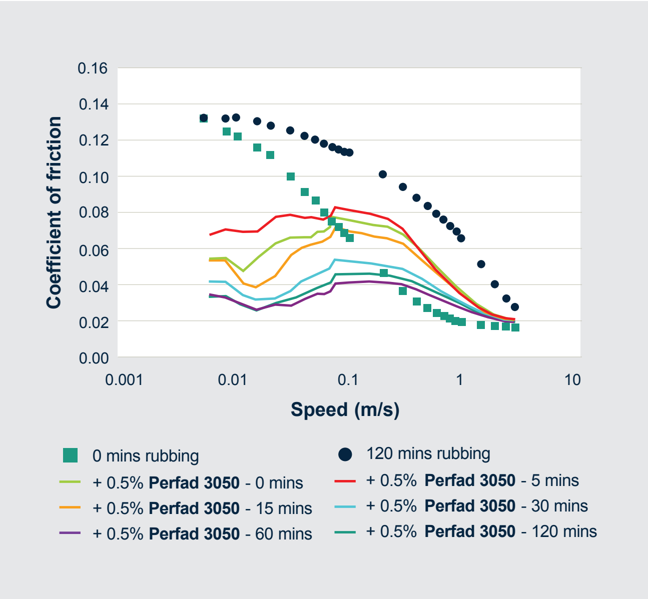


Figure 15 Pre-conditioned European engine oil ball and disc with subsequent top-treat of Perfad. Tested at 135°C

In reality, surfaces are rarely virgin but pre-conditioned either during manufacture or during use it is practical to consider the influence of friction modifiers on a pre-conditioned disc. This testing provides an indication as to the friction properties which may be experienced following an oil change.

Figure 15 shows the result of the initial and post 120 minute rubbing Stribeck curve for the European engine oil at 135°C. After the test, the pre-conditioned ball and disc remained in the machine and the European engine oil was drained from the system and replaced with a fresh sample of European engine oil + 0.5% Perfad 3050. The coefficient of friction decreased immediately as the polymeric friction modifier began to adsorb onto the polyphosphate film, and continued to decrease as the polymeric friction modifier film developed.

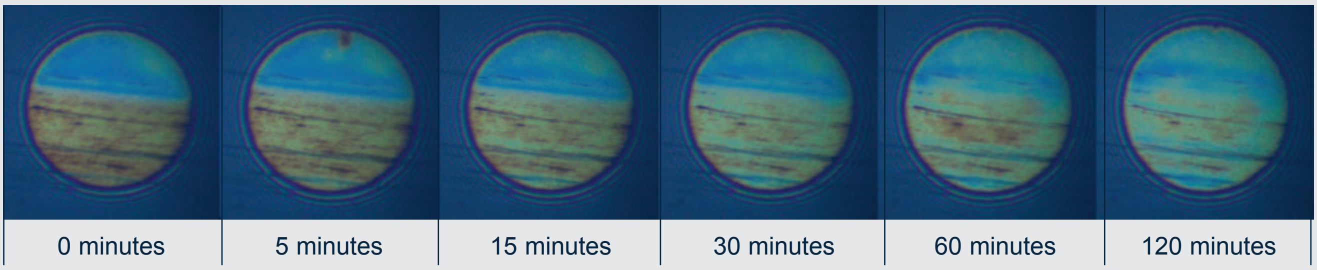


Figure 16 Interference images of pre-conditioned ball and disc with subsequent top-treat of Perfad

Figure 16 shows the corresponding interference images of the Stribeck curves in Figure 15. The colour becomes lighter with rubbing time, demonstrating that **Perfad 3050** builds on top of the polyphosphate film on the surface of the ball.

Similar effects can be observed for **Perfad 3000** and **Perfad 3006** and in North American, Japanese, European and other regional style engine oils.

Steel-on Steel contacts - sliding friction and wear

Polymeric friction modifiers provide reduced friction and reduced wear compared to conventional engine oils and conventional organic friction modifiers

Tests were conducted using the SRV®5 technology platform at the headquarters of Optimol Instruments in Munich, Germany, using the conditions shown in Table 5.

Parameter	Value
Load	50 N (30 seconds run in) 200 N (30 minutes)
Temperature	130°C
Stroke length	3 mm
Frequency	20 Hz
Cylinder liner	Grey cast iron
Piston ring	X70CrMo15

Table 5 SRV®5 test conditions

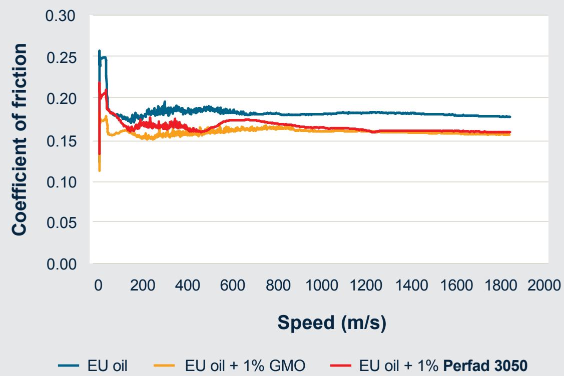


Figure 17 SRV®5 results

Figure 17 shows the friction results of the European engine oil with and without the addition of GMO and Perfad 3050 using a section of a genuine piston ring and cylinder liner. Once steady state friction is achieved, GMO and Perfad 3050 perform comparably with a 10% reduction in friction versus the untreated European engine oil.

Analysis of the wear scars through contact profilometry (Figure 18) demonstrates that Perfad 3000, Perfad 3006 and Perfad 3050 provide significantly improved wear performance compared to conventional organic friction modifiers.

- GMO increased the wear scar by 10%
- **Perfad 3050 decreased the wear scar by 20%**

Similar performance can be achieved with Perfad 3000 and Perfad 3006 in a range of regional style engine oil formulations.

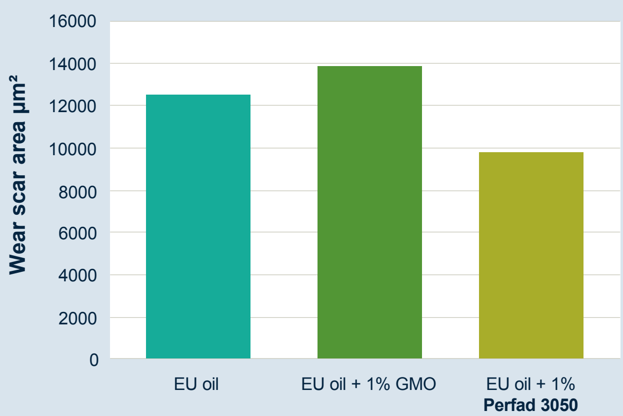


Figure 18 Wear scar results for European engine oil + friction modifiers

Diamond-like carbon coating

Polymeric friction modifiers provide unrivalled friction reducing performance on diamond-like carbon

Diamond-like carbon (DLC) is an emerging technology that has the potential to reduce friction and improve component durability within a range of applications. DLC coatings are typically applied to provide a low friction surface and/or a more durable surface, and often a combination of the two. The introduction of novel coatings clearly has great advantages but the material of construction within the engine and lubricant design must be complimentary to each other, thus ensuring the performance of the engine is maintained throughout the drain interval period and onwards.

'Polymeric friction modifiers have been shown to provide low friction and improved wear performance on two types of DLC coatings; hyrdogenated DLC, 50% sp3 hybridisation and non-hydrogenated and Cr doped DLC. Polymeric friction modifiers outperform conventional friction modifiers including GMO and MoDTC.

The mini traction machine sliding/rolling friction method described on page 2 was used to create the results in Figure 19 and 20.

Steel ball - DLC disc contact – 85% reduction in friction in the boundary regime

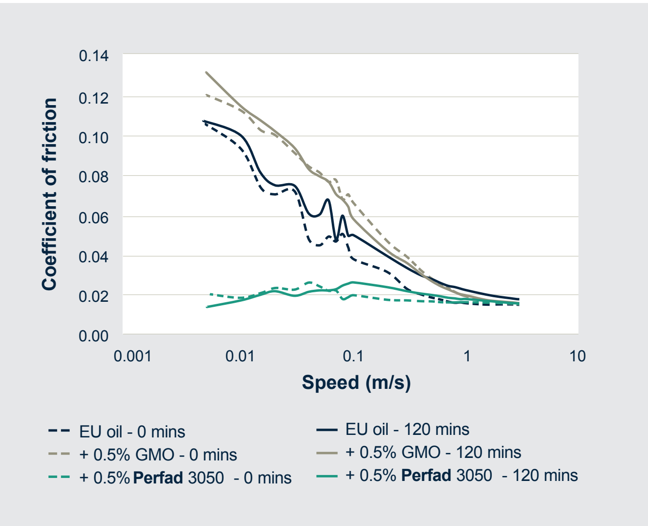


Figure 19 MTM results for European engine oil + friction modifiers at 135°C (steel ball DLC coated disc, hydrogenated DLC, 50% sp³ hybridisation)

On sp³ type DLC coating:

- GMO increased friction by 13%
- **Perfad 3050 decreased friction by 85%**

Similar results are observed for Perfad 3000 and Perfad 3006.

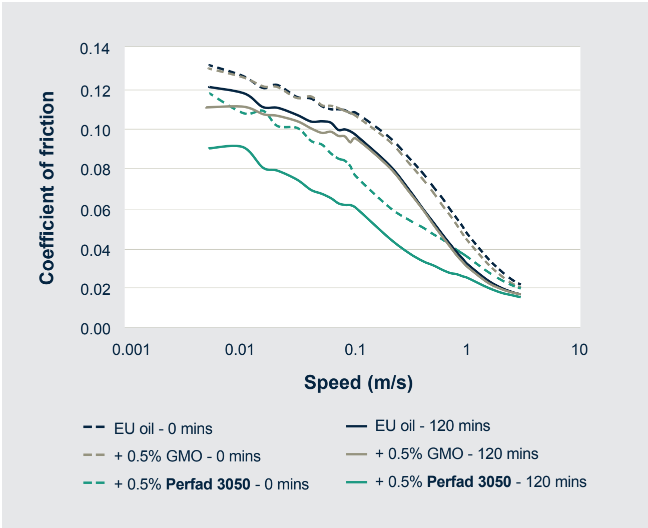


Figure 20 MTM results for European engine oil + friction modifiers at 135°C (DLC coated ball, DLC coated disc, hydrogenated DLC, 50% sp³ hybridisation)

DLC ball - DLC disc contact - 25 to 40% reduction in friction in the boundary and mixed regimes

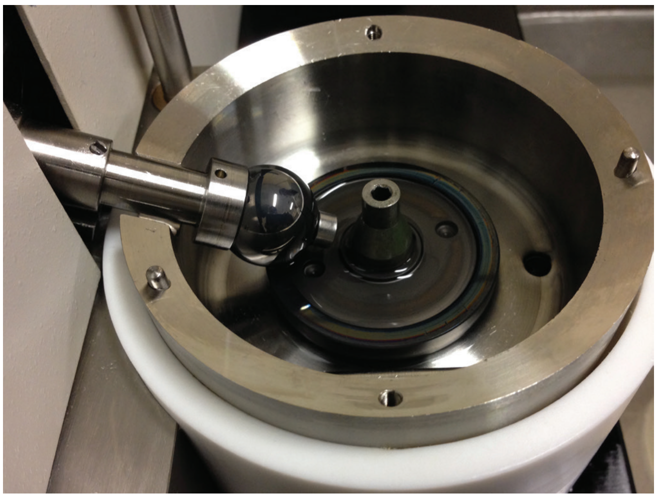


Figure 21 Diamond-like carbon (DLC) coated disc set up in the mini traction machine

Geometry of contacts

Polymeric friction modifiers can significantly reduce friction on different types of DLC coatings and in a range of ball-disc configurations. A summary of some results are shown in Table 6 and 7 below.

Configuration disc-ball	S-S	hDLC-S	S-hDLC	nhDLC-S	S-nhDLC	hDLC-hDLC	nhDLC-nhDLC
CoF of EU oil	0.131	0.105	0.115	0.122	0.134	0.113	0.093
CoF of EU oil + 0.5% GMO	0.103	0.120	0.105	0.124	0.120	0.111	0.085
CoF of EU oil + 0.5% Perfad 3050	0.021	0.020	0.018	0.043	0.039	0.101	0.080
GMO CoF reduction %	21	-14	8	-2	9.9	1.2	7.8
Perfad 3050 CoF reduction %	84	81	84	65	71	11	13

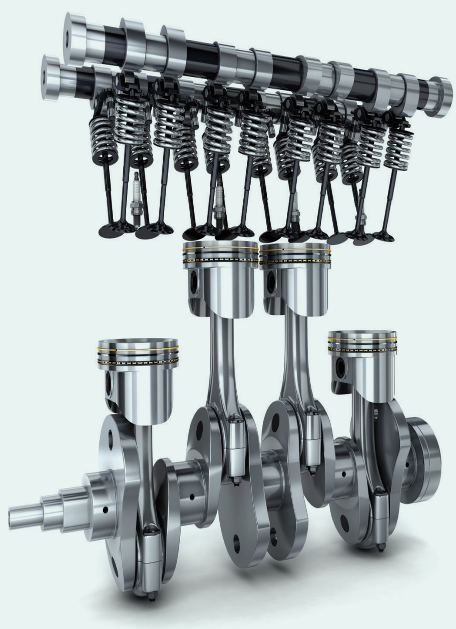
Table 6 MTM coefficient of friction results for European engine oil + friction modifiers at 0 minutes rubbing at 135°C (0.005 m/s) S – steel, hDLC - hydrogenated DLC, 50% sp^3 hybridisation, nhDLC - non-hydrogenated and Cr doped DLC

Configuration disc-ball	S-S	hDLC-S	S-hDLC	nhDLC-S	S-nhDLC	hDLC-hDLC	nhDLC-nhDLC
CoF of EU oil	0.131	0.107	0.120	0.136	0.117	0.103	0.100
CoF of EU oil + 0.5% GMO	0.120	0.131	0.091	0.127	0.121	0.095	0.097
CoF of EU oil + Perfad 3050	0.010	0.013	0.010	0.046	0.034	0.077	0.095
GMO CoF reduction %	9	-23	24	6	-3	9	3
Perfad 3050 CoF reduction %	92	88	92	66	71	26	6

Table 7 MTM coefficient of friction results for European engine oil + friction modifiers at 120 minutes rubbing at 135°C (0.005 m/s) S – steel, hDLC - hydrogenated DLC, 50% sp^3 hybridisation, nhDLC - non-hydrogenated and Cr doped DLC

Perfad 3000 and Perfad 3006 are also highly active in reducing friction on DLC surfaces.

Polymeric friction modifiers have the potential to not only reduce friction on orthodox surfaces but also on new surfaces such as DLC, offering lubricant formulators a novel and versatile additive technology



Solubility

The solubility of friction modifiers is dependent on the formulation style of the engine oil. It is highly recommended that Perfad 3000, Perfad 3006 and Perfad 3050 are all considered in order to identify the appropriate friction modifier for individual formulation styles.

No harms testing

Polymeric friction modifiers exhibit the following features and benefits:

- Negligible effects on low temperature and HTHS viscosity
- Excellent shear stability
- No negative effects on foaming
- Good oxidative stability

European engine oil was top-treated with 0.5% Perfad 3050 and typical global specification tests were conducted. Perfad 3050 was selected for the majority of tests for demonstrative purposes. Perfad 3000 and Perfad 3006 display similar no harms performance.

Low temperature pumpability

Formulation	MRV viscosity -35°C (mPa.s)	Yield stress	Yield stress – value
EU oil	25 200	No	< 35
+ 0.5% **Perfad 3050**	25 500	No	< 35

Table 8 MRV results (CEC L-105-12)

HTHS viscosity

Formulation	HTHS dynamic viscosity (mPa.s)
EU oil	3.52
+ 0.5% **Perfad 3050**	3.58

Table 9 HTHS results (CEC L-36-A-90)

Oxidative stability

Formulation	OIT1 (min)	OIT2 (min)	Mean OIT (min)
EU oil	16.4	17.4	17
+ 0.5% **Perfad 3050**	17.2	18.5	18

Table 10 PDSC results (ASTM D6186)

Foaming

Parameters	EU oil	+ 0.5% Perfad 3050
Foaming tendency seq I (ml)	Nil	Nil
Foaming stability seq I (ml)	Nil	Nil
Foaming tendency seq II (ml)	20	20
Foaming stability seq II (ml)	Nil	Nil
Foaming tendency seq III (ml)	Nil	Nil
Foaming stability seq III (ml)	Nil	Nil

Table 11 Foaming results (ASTM D892)

Parameters	EU oil	+ 0.5% Perfad 3050
Foaming tendency (static foam, ml)	100	90
Foaming stability after 5 s (ml)	50	40
Foaming stability after 15 s (ml)	Nil	Nil
Collapse time (after 5 min blowing, s)	11	12
% Total volume increase	30	20
Total volume increase (ml)	60	40
Kinetic foam before air disconnect (ml)	110	110
Total volume before air disconnect (ml)	260	240

Table 12 High temperature foaming results (ASTM D6082)

Corrosion

	Corrosion - 0h		Corrosion - 168h	
Formulation	EU Oil	+ 0.5% Perfad 3050	EU oil	+ 0.5% Perfad 3050
Element content Cu mg/kg	<1	<1	7	12
Element content Pb mg/kg	<1	<1	10	177
Element content Sn mg/kg	<1	<1	<1	<1
Corrosion grade (Cu)	-	-	1a	1a

Table 13 Corrosion results (ASTM D6594)

Similar no harms properties can be observed for Perfad 3000 and Perfad 3006 and in a range of regional style engine oil formulations.

Shear stability

Shear stability testing was performed using 5% polymeric friction modifier in Group II base oil. Perfad 3000, Perfad 3006 and Perfad 3050 retain their structure even under severe shear conditions (Figures 22, 23 and 24). In comparison, conventional viscosity modifiers (VMs) generally break down when sheared, for example an olefin copolymer VM as shown in Figure 25.

Perfad 3000, Perfad 3006 and Perfad 3050 demonstrate excellent shear stability, meaning they will retain their friction reducing capabilities even as the engine oil shear thins

MW distribution of fresh samples and after 20 hours KRL shear-stability test - Perfad 3000

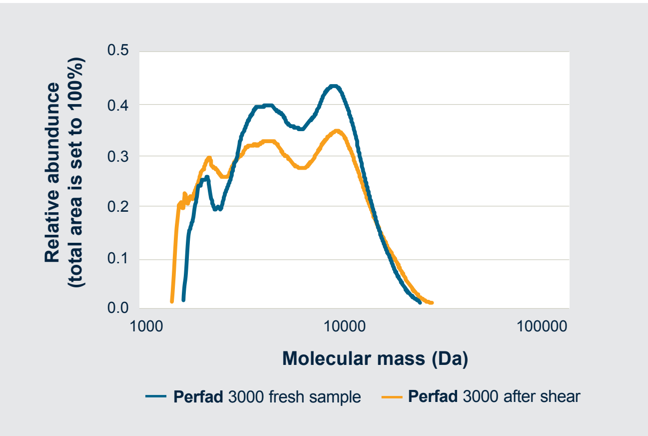


Figure 22 Gel permeation chromatography results for Perfad 3000

MW distribution of fresh samples and after 20 hours KRL shear-stability test - Perfad 3006

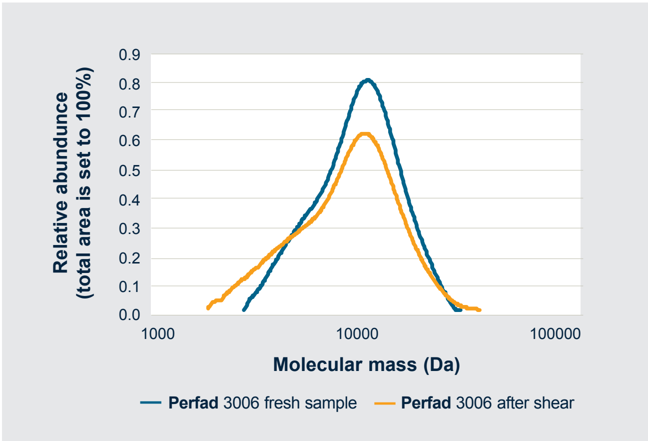


Figure 23 Gel permeation chromatography results for Perfad 3000

MW distribution of fresh samples and after 20 hours KRL shear-stability test - Perfad 3050

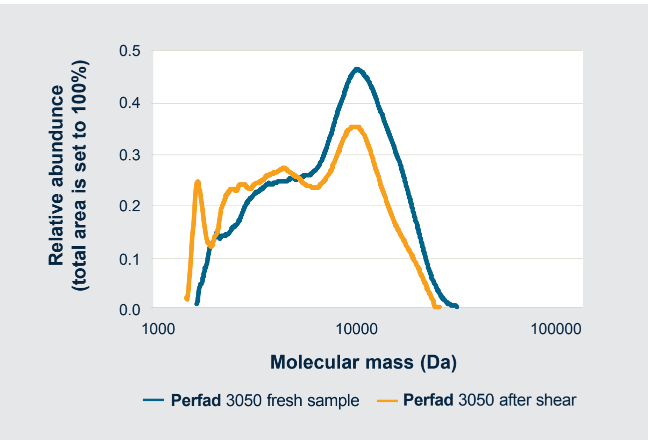


Figure 24 Gel permeation chromatography results for Perfad 3050

MW distribution of fresh samples and after 20 hours KRL shear-stability test - OCP VM

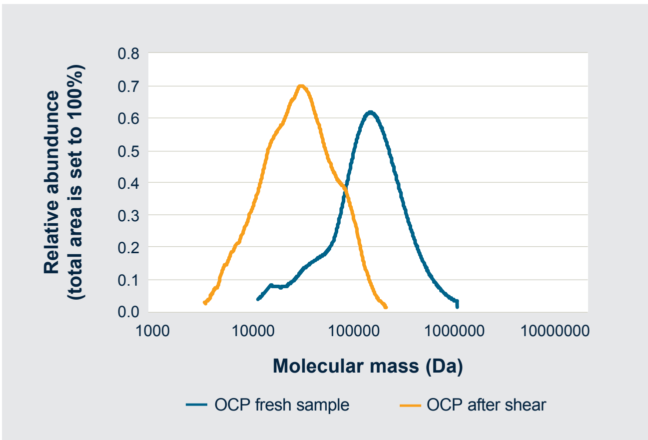


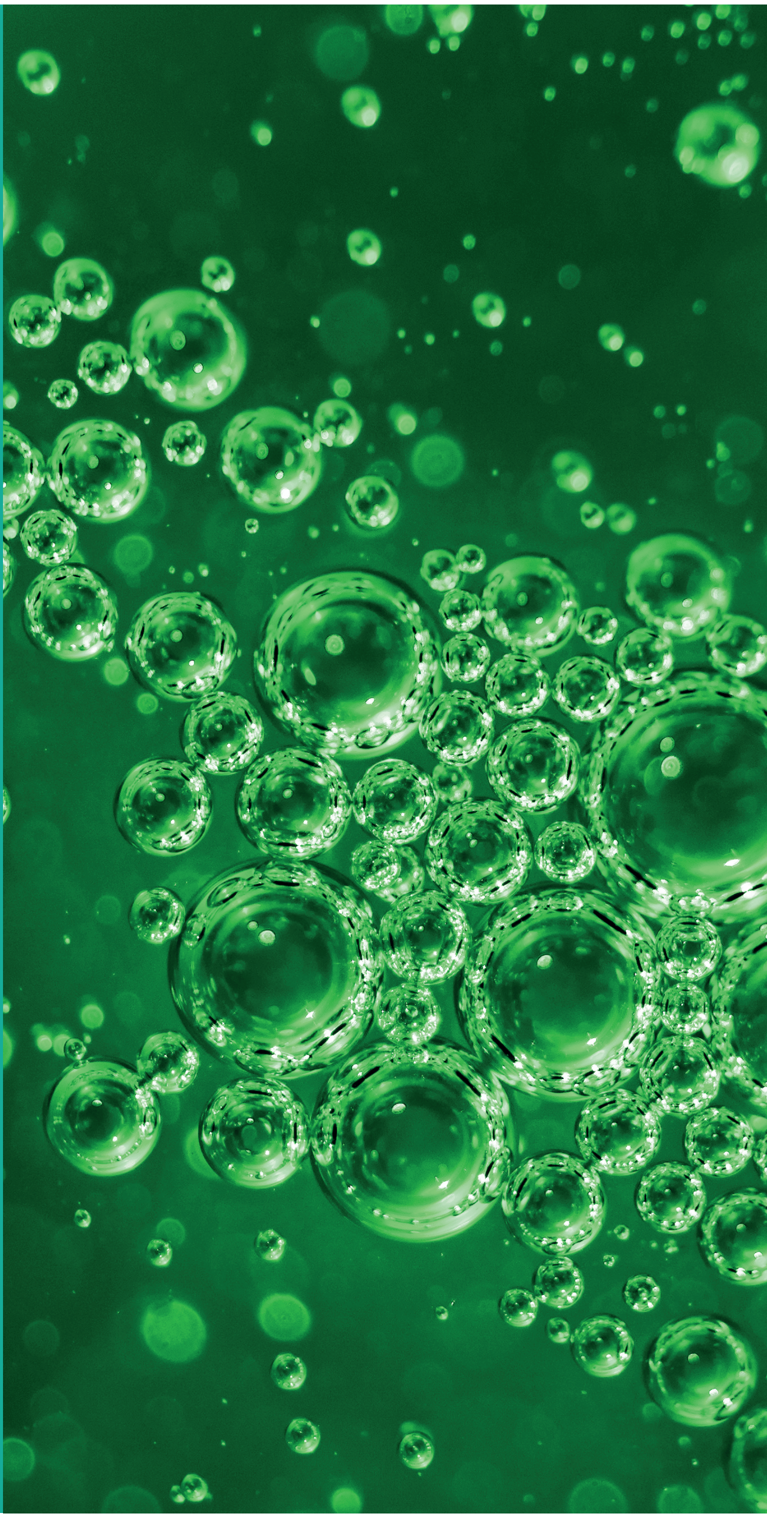
Figure 25 Gel permeation chromatography results for olefin copolymer viscosity modifier

Formulating with Perfad 3000, Perfad 3006 and Perfad 3050

Perfad 3000, Perfad 3006 and Perfad 3050 are a new generation of SAPS free friction modifiers, exhibiting outstanding friction reducing characteristics in base oils and in formulated engine oils. Perfad 3000, Perfad 3006 and Perfad 3050 offer the potential to reduce friction and to contribute to both fuel efficiency improvements and the reduction of emissions. Compared with anti-wear additives and inorganic friction modifiers, such as ZDDP and MoDTC, they are more active at lower temperatures and have the potential to reduce engine wear by acting synergistically with such inorganic additives.

When formulating with Perfad 3000, Perfad 3006 and Perfad 3050:

- We recommend testing Perfad 3000, Perfad 3006 and Perfad 3050 in a range of formulations to determine their suitability and effectiveness
- Their effective use is dependent upon using other additives which are compatible and which do not act antagonistically with them
- Some components within some engine oils are surface active or highly solubilising and can stop friction modifiers reaching the metal surfaces and therefore prevent them from reducing friction between moving parts
- In formulating the engine oil, we recommend blending Perfad 3000, Perfad 3006 and Perfad 3050 with the most polar additives first before blending into the less polar components, such as the base oil



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Who are we?

The Energy Technologies business in Cargill Bioindustrial creates, makes and sells specialty chemicals and additives for the global energy market. Working in close collaboration with our customers, we apply sustainable concepts and deep scientific expertise so that together we can efficiently power the world of tomorrow.

At our core, we are experts in synthetic ester and polyalkylene glycol chemistries, taking products from lab scale through to full manufacturing. Investing in the development of new chemistries allows us to support our customers in meeting new industry challenges.

For those who dare to imagine a brighter future, we establish long lasting relationships and create bespoke industry solutions through our integrated research & development and global manufacturing capabilities. Being both global and local, you have direct access to our network of technical experts. We look forward to talking to you.

Further information

Cargill Bioindustrial sales and distribution are coordinated through an extensive worldwide network of technical and commercial experts. For further information or guidance please contact us:

energy_technologies@cargill.com