

Formulating Gear Oils With Functional Products

September 2020



- Wide range of lab and gearbox tests for most gear oil specifications
 - ANSI/AGMA 9005 industrial gear
 - SAE J306 automotive gear
- **First things** to get right at the start of a project are:
 - Shear Stability & Viscosity Index
 - Functional M Series polymethacrylate viscosity modifiers
 - Extreme pressure protection
 - Functional GA gear oil packages



- Tapered bearing roller (KRL) test
 - Also known as: “20 hr KRL”, CEC L-45-99-A, DIN 51350-6, ISO 26422
- Most industrial and OEM fluids require $< 15\%$ viscosity loss by 20hr KRL
 - Some OEMs may require $< 10\%$ viscosity loss instead
- Most Group I/II/III and bright stocks will have negligible shear
- Polybutenes and mPAO - $< 5\%$ loss in 20hr KRL
- Typically fluids VI < 140 are shear stable



- High VI gear oils
 - AGMA 9005 specifies proper ISO VG for application based on VI
 - VI 90, 120, 160, 240
 - Higher VI, less temperature effect on viscosity, wider operating temp.
 - “Multi-grade” or “all season”
 - Also tends to have low pour points, low temp fluidity, etc.
- To make higher VI fluids requires high MW polymers, “VI improvers”
 - Polymers are large enough to influence VI and give VI > 140
 - Also large enough to shear in KRL if not chosen carefully



- High VI gear oils require a balance between base oil viscosity and how much viscosity is added by shearable polymer

	Benefit	Challenge
Add More VI Improver	Higher VI Better low temp Brookfield viscosity and pour point Higher solvency and clarity w/ synthetic base oils	Higher viscosity loss in KRL Added cost
Increase Base Oil Viscosity	Reduced viscosity loss by KRL Lower cost (situational)	Lower VI Requires more wt% VI improver to improve VI Worse low temp fluidity (Brookfield, pour point)

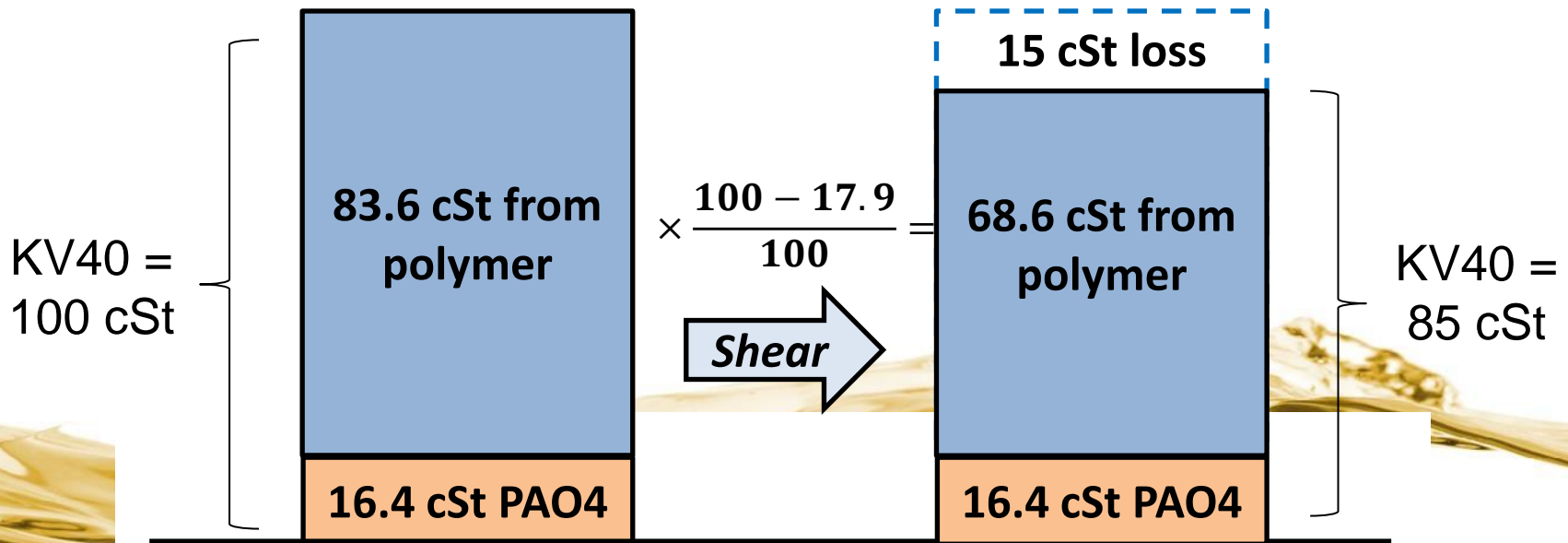
- Shear Stability Index (SSI)
 - Typically defined by Kurt-Orbahn diesel injector method (ASTM D6278)
 - Maybe also be defined with respect to sonic shear or KRL
- $SSI = \% \text{ of viscosity added by polymer that is lost in the shear method}$
 - SSI 25 means if you add 100 cSt then 25 cSt (25%) will be lost to shear



- What SSI do need to get < 15% loss by KRL for a given ISO VG?
 - Need to know polymer SSI and what base oil you'll use
- Example: Making an ISO 100 from PAO4...

$$\% \text{Visc Loss} = \% \text{Visc from Polymer} \times \frac{SSI}{100}$$

$$SSI \text{ Required} = \frac{100 \times \% \text{Visc Loss}}{\% \text{Visc from Polymer}} = \frac{100 \times 15}{83.6} = 17.9$$



- Options at Functional:
 - M Series polymethacrylates
 - FUNCTIONAL MG-1000, MG-3000, MH-2000
 - 15 – 35% SSI by KRL
 - High viscosity synthetic base stocks
 - FUNCTIONAL V-736 / V-731 / V-732 ethylene propylene oligomers
 - 5 - 15 SSI by KRL
- Exceptional shear stability in KRL to formulate a high range of low and high viscosity gear oils with high VI



	Thickening Efficiency	Shear Stability	Typical Applications				Preferred Base Fluid Type	
KV100 (cSt)	KV100, 10wt% (cSt*)	KRL 20 hr.	ISO 32-150 Industrial Gear / HF	ISO 220+ Industrial Gear / HF	Auto Gear 75W-90	Auto Gear 75W-140	Group I/II	Group III/VI/V

Industrial and Automotive Gear PMA

MG-1000	900	8.6	15%		X	X	PAO	VI
MG-3000	550	8.0	20%		X	X	PAO	I/II III
MG-1500	1200	9.6	25%	X		X	PAO	I/II III/VI
MG-1860	900	9.1	30%	X		X	PAO	VI/V

Hydraulic Fluid PMA

MH-2000	1100	9.2	35%	X				I/II
---------	------	-----	-----	---	--	--	--	------

Dispersant PMA

MD-2200	900	8.9	35%	X		X	PAO	I/II III/VI
----------------	-----	-----	-----	---	--	---	-----	-------------

NEW for 2020

PMA Comparison

MG-3000

Optimized for paraffinic
automotive gear low temp.

20 SSI by KRL



MG-1000

Optimized for PAO
automotive gear low temp.

15 SSI by KRL

MG-1500

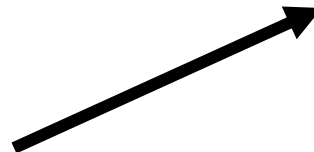
Optimized for Gr. III/IV

25 SSI by KRL

MH-2000

Workhorse PMA for Gr. I/II

35 SSI by KRL



MG-1860

PAO-based MH-2000, no oil

30 SSI by KRL

MD-2200

Dispersant MH-2000

35 SSI by KRL



- Functional MH-2000 - 35 SSI by KRL
 - Works best in Group I/II at ISO 32 – 150 for high VI gear
- Functional MG-1500 – 25 SSI by KRL
 - Optimized for Group III/IV automotive gear and low visc industrial gear
- Functional MG-1860 – 30 SSI by KRL
 - Prepared in PAO, no mineral oil content for 100% synthetic gear oil

VI 140 EP Gear Oils, shear in grade by KRL

wt%	ISO 32	ISO 46	ISO 68	ISO 100	ISO 150
110N Gr. II	77.7	60.9	43.6	29.4	10.1
600N Gr. II	18.8	33.6	47.4	57.4	74.1
<u>MH-2000</u>	1.5	3.5	7.0	11.2	13.8
Gear Package	2.0	2.0	2.0	2.0	2.0
KV40	29.5	43.6	68	104.8	158.1
KV100	5.8	7.5	10.4	14.3	19.5
VI	141	140	140	140	141

- VI >140 at ISO 220+ requires very shear stable PMA
 - Heavy base oils can't produce high VI, requires light base oil
 - Light oil and high product viscosity requires very shear stable PMA
- Functional MG-3000
 - 20 SSI by KRL; use in Group I/II/III gear oils, gives best low temp flow
- Functional MG-1000
 - 15 SSI by KRL; use in Group IV gear oil or extra high shear stability

VI 140 EP Gear Oils, shear in grade by KRL

wt%	ISO 220	ISO 320	ISO 460	ISO 680	ISO 1000
110N Gr. II	13.0	7.0	--	--	--
600N Gr. II	64.0	65.0	67.5	60.8	54.4
<u>MG-1000</u>	21.0	26.0	30.5	37.2	43.6
Gear Package	2.0	2.0	2.0	2.0	2.0
KV40	219.6	320	473.6	702.2	1043.5
KV100	24.5	32.2	42.4	55.9	72.7
VI	140	141	140	140	140
EP Weld (D2596)	315	315	315	315	315

- Gears used to transmit mechanical power
 - Heavy loads applied over small gear teeth creates high pressure
 - High pressure can push through fluid film and cause metal contact
 - Scuffing or scoring of metal → gear damage and failure
- ASTM D2783 – 4-ball extreme pressure
 - One of many methods for evaluating EP protection
- EP protection level varies based on gear design and application
 - Typically denoted by API Service Category (GL-1 to GL-5)



API Service Category	Active Components Typically Used in the Gear Oil	Application	Typical 4-Ball EP Weld Load (D2783)	Functional Products Option
GL-1	Straight mineral oil (CI, AO, PPD, defoam)	<i>Obsolete</i>	≤ 100 kgf	0.3% CI-426 0.1% PD-610
GL-2	AW and FM allowed (fats/esters)	Worm gear (Brass/Steel)	<i>Varies</i>	1.5% WA-60SF
GL-3	Mild EP included (phos. and sulfur EP)	Manual transmissions, light to severe; spiral bevel gears	200 – 250 kgf	1.75% WA-64
GL-4 **	Strong EP included (active sulfur)	Most manual transmission; hypoid gears	315 - 400 kgf	2.8% GA-614
GL-5 **	Same as GL-4	High speed/torque hypoid, heavy duty vehicles	315 - 500 kgf	4.0% GA-614

** GL-4 LS
or GL-5 LS

Friction modifier added to
GL-4 or GL-5

Limited slip differential
(with clutch pack)

315 – 500 kgf



- **Functional GA-614**
 - Metal-free industrial gear package
 - 1.5 – 5.0wt% treat
 - 2.8wt% meets US Steel 224; DIN 51517-3 CLP; ISO 6743-6
 - 4.0wt% suitable for API GL-5 extreme pressure performance

- Light color, low odor
- FZG 12+ stage pass
- 60+ Timken OK load
- 620 kgf EP weld at 5wt%

Typical Properties	
Odor and Appearance	Mild, hazy liquid
Demulsibility (D1401) at 30 minutes	39/41/0
Lbs per Gallon	8.4
Flash Point (COC)	150°C
Kinematic Viscosity at 40°C	65 cSt
Copper strip corrosion (D130), 3 hrs., 100°C	1b
Sulfur	29.3 wt%
Phosphorous	1.4 wt%
Test Results - Formulated at 2.8% in ISO 220 mineral oil	
Turbine Oil Rust Test (D665A and B)	Pass
4-Ball Wear Scar (D4172, 20 kg)	0.33 mm
4-Ball Weld Load (D2783)	315 kg
Load wear Index (LWI)	66
Timken OK Load (D2782)	> 60 lbs
Oxidation Test (D2893), Viscosity change	0.28 %
Precipitation Number	0.02 ml
Foam (D892), Sequence I, II, III	00/00
FZG A/8.3/90 (D5182), Load stage	> 12

- FUNCTIONAL CI-426EP
 - Amine phosphate-based corrosion inhibitor with added EP protection
- FUNCTIONAL pour point depressants
 - PD-610 for ISO 46+ Group I/II
 - PD-620 for 4 cSt Group III
 - PD-630 for 6 and 8 cSt Group III
- Tackifiers for open gear and mist-resistant lubricants
 - V-176 for workhorse tackifier
 - V-188 for added shear stability and long service life
 - V-388 for synthetic and high temp gear oils



- Functional Products supplies products and insight to help formulators create high end industrial and automotive gear oils
 - Shear stable polymethacrylates for mineral oil and synthetic formulas
 - Functional MG-1000, MH-2000, etc.
 - Gear oil packages
 - Functional GA-614 package with variable treat rate
 - Individual components
 - Tackifiers, PPDs, corrosion inhibitors

