New EPO Base Stocks
FUNCTIONAL V-731 & V-732

June 2021

2020/2021 - High performance viscosity

- FUNCTIONAL V-700 series
  - Pure, highly shear stable viscosity modifiers and base stocks
    - Always ≤ 10% PSSI, 30 cycle K-O
    - Polyolefin chemistry
    - Typically liquid but some flake options

V-700 Series Entries

- V-705 – ISO 37,000 low temperature base stock
- V-711 – 10 SSI styrene olefin copolymer flake
- V-720 – ISO 25,000 biobased high solvency thickener

- **V-731 & V-732 – 1100 and 2000 cSt ethylene propylene oligomers**
  - **NEW** for June 2021
  - Also a High Viscosity Synthetic Basestock

2020/2021 - High Viscosity Synthetic Base Stocks

- High Viscosity Synthetic Base Stocks – “HVSB”
  - Always ≤ 15 SSI by 20hr KRL
  - High viscosity, >600 cSt @ 100C
  - Excellent low temperature fluidity
  - Able to meet HVLP hydraulics, OEM gear, and more

- Previously includes:
  - FUNCTIONAL V-705 (polyolefin)
  - FUNCTIONAL MB-1010 (PMA)

V-731 and V-732 EPO Properties

	FUNCTIONAL V-731	FUNCTIONAL V-732	
KV100, cSt	1100	2000	
KV40, cSt	18,900	37,500	
Viscosity Index, Typical	270	300	
Pour Point, D97	-6C / 21F	-3C / 27F	
Flashpoint, D92	>290C / 554F	>290C / 554F	
NOACK, D5800	< 0.3%	< 0.2%	
lb/gal @ RT	7.13	7.12	
Specific Gravity	0.84	0.84	
Thickening Efficiency @ 100C	11.5	13.7	*10wt% in ISO 32 Gr. I*
PSSI by ASTM D6278 30 cycle	0 SSI	0 SSI	
SSI by 20hr KRL	8 SSI	13 SSI	
Color, D1500	$\leq$ 0.5	$\leq$ 0.5	
Total Acid Number, D664	0.01	0.01	
Aniline Point, D611	>170C	>170C	

Open head drums, 352.7 lbs. net weight per drum

FUNCTIONAL PRODUCTS INC.
Innovative Chemistry for Lubricants

EPO Chemistry

- Ethylene-Propylene Oligomer

- CAS# 9010-79-1
- TSCA, globally registered
- 100% pure and undiluted

"oligomer" = very small polymer, typically a couple hundred repeat units and 1000's to 10000's of MW or less

V-731 and V-732 Applications

- Industrial and automotive gear oil
- Automotive gear oil (GL-4, GL-5, MT-1, etc.)

	1100 cSt (V731)	2000 cSt (V732)
75W-90 in PAO	Yes	Yes
75W-90 in Gr. III	Yes	Yes
75W-140 in PAO	Yes	Not Yet
75W-140 in Gr. III	Yes	Not Yet

- Hydraulic fluid (HVLP, EAL)
- Synthetic greases
- High temp chain and oven lubricants
- Sugar mill, mining, oil exploration

- *NSF HX-1 and European Ecolabel pending*

EPO Compatibility

- 10wt% in various base stocks
- Freeze/thaw at -30C overnight
  - Then store at RT for 1 month
- One of few VMs that mixes with mPAO
  - Slight haze is okay for grease

Base Stock	*FUNCTIONAL V-731 (1100 cSt)*	*FUNCTIONAL V-732 (2000 cSt)*
Group I – III	***Clear and Compatible***	***Clear and Compatible***
Naphthenic Oil	***Clear and Compatible***	***Clear and Compatible***
Low Viscosity PAO	***Clear and Compatible***	***Clear and Compatible***
mPAO	*Slight Haze*	*Slight Haze*
Alkylated Naphthalene	***Clear and Compatible***	***Clear and Compatible***
WS PAG 32	*Separates*	*Separates*
WI PAG 32	*Separates*	*Separates*
OS PAG 32	*Delayed Separation*	*Delayed Separation*
Canola	***Clear and Compatible***	***Clear and Compatible***
DIOA (short chain adipate)	*Delayed Separation*	*Delayed Separation*
DTDA (long chain adipate)	***Clear and Compatible***	***Clear and Compatible***
TMP C8-C10 (short chain polyol)	*Delayed Separation*	*Delayed Separation*
TMP C18 (long chain polyol)	***Clear and Compatible***	***Clear and Compatible***
Estolide ISO 22	***Clear and Compatible***	***Clear and Compatible***

Properties vs. Applications

- Shear stable
  - OEM industrial and automotive gear, HVLP hydraulics, ATF
- Very high viscosity
  - Mining, rock crusher, sugar mill, grease, wire rope
- Very high flashpoint, low VOC/NOACK, and odorless
  - High temp chain oils, air and gas compressors, pellet mill
  - Open gear and spray lubrication systems
  - Metalforming, quenchants, smokeless oils

EPO / mPAO/ PB Viscometrics

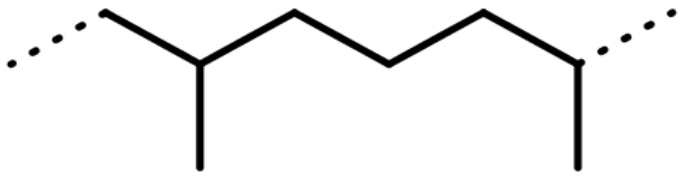
- For ISO visc grades – V-732 is highest KV40 with reasonable handling visc

	KV20	KV40	KV100	VI	Pour, D97	Flash, D92	lb/gal
FUNCTIONAL V-731	72,700	18,900	1,100	272	-6°C	295°C	7.1
FUNCTIONAL V-732	148,000	37,500	2,000	299	-3°C	295°C	7.1
mPAO 100	3,310	1,040	100	189	-42°C	265°C	7.0
mPAO 150	5,590	1,700	150	199	-42°C	268°C	7.0
mPAO 300	10,600	3,360	300	239	-33°C	286°C	7.0
PB 950 MW	28,000	5,400	220	147	-5°C	180°C	7.4
PB 1300 MW	107,000	19,400	640	188	5°C	200°C	7.5
PB 2600 MW	1,070,000	180,000	4,450	273	15°C	100°C	7.6

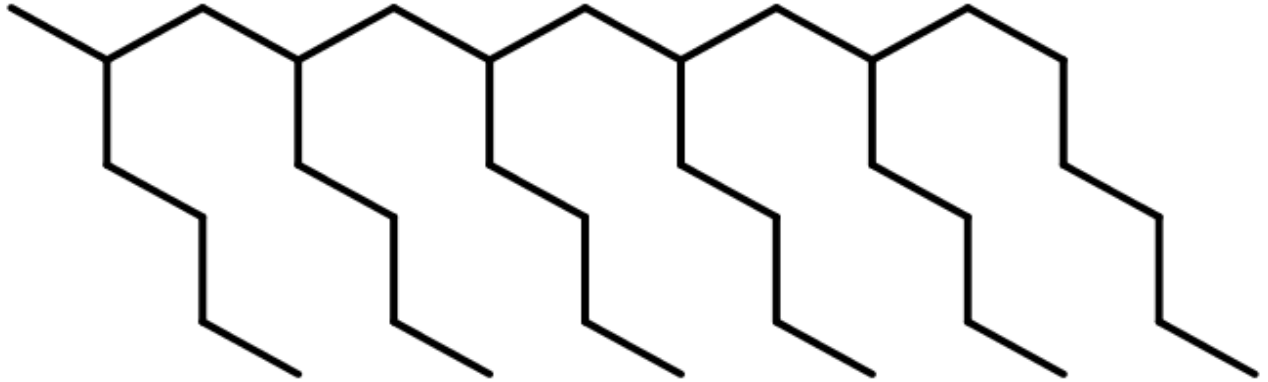
EPO vs. mPAO

- EPO offers lower treat rates over mPAO 100/150/300
  - Less polymer, more low viscosity base fluid
    - Better low temp fluidity
    - Better additive compatibility (no ester required to compatibilize)

EPO



mPAO

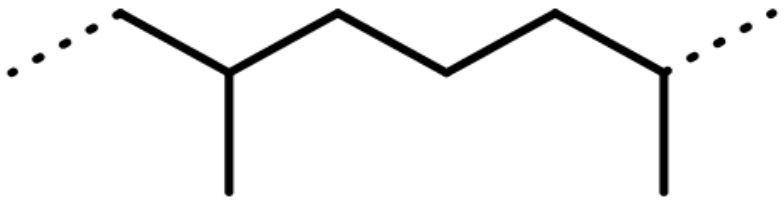


EPO vs. Polybutenes

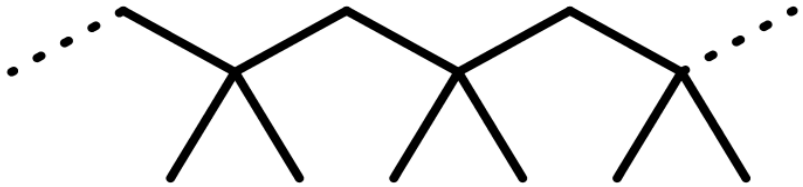
- EPO more heat resistant – PIB thermally unstable (unzips at high T)
  - EPO flashpoint = ~295°C
  - PIB flashpoint = ~200°C

- High density – less favorable $/gal pricing in final formula

EPO



PIB



- Plus same benefits of EPO vs. mPAO

75W-90 Formulation Work w/ V-731

- Let Functional design and optimize your 75W automotive gear oils
  - Using your existing raw materials whenever possible

Formula by wt%	*Role*	75W-90 Gr. III	75W-90 PAO	
FUNCTIONAL V-731	*VM*	16.0%	16.5%	
4 cSt Group III	*Base Oil*	76.0%		
PAO 4	*Base Oil*		73.5%	
GL-5 Package A	*EP Package*	7.5%		*Supplier A*
GL-5 Package B	*EP Package*		10.0%	*Supplier B*
FUNCTIONAL PD-630	*Gr. III PPD*	0.5%		
KV100, cSt	*D445*	16.3	15.4	*>13.5 for 90, >24.0 for 140*
20hr KRL Viscosity	*CEC L-45-A-99*	15.3	14.5	*>13.5 for 90, >24.0 for 140*
BF Visc @ -40C, cP	*D2983*	53,400	83,800	*< 150,000 cP*

75W-140 with V-731 are TBD

75W-140 Formulation Work w/ V-731

Formula by wt%	*Role*	75W-140 Gr. III	75W-140 PAO	
FUNCTIONAL V-731	*VM*	23.6%	24.8%	
4 cSt Group III	*Base Oil*	53.4%		
PAO 4	*Base Oil*		55.2%	
4 cSt Adipate Ester	*Base Oil*	15.0%	10.0%	
GL-5 Package A	*EP Package*	7.5%		*Supplier A*
GL-5 Package B	*EP Package*		10.0%	*Supplier B*
FUNCTIONAL PD-630	*Gr. III PPD*	0.5%		
KV100, cSt	*D445*	25.9	26.2	*>24.0 for 140*
20hr KRL Viscosity	*CEC L-45-A-99*	24.1	24.4	*>24.0 for 140*
BF Visc @ -40C, cP	*D2983*	130,400	132,000	*< 150,000 cP*

75W-140 with V-731 are TBD

Paraffinic 75W-90 w/ V-732

Formula by wt%	*Role*	75W-90 Gr.II	75W-90 Gr.II+	75W-90 Gr.III	
FUNCTIONAL V-732	*VM*	13.0	13.0	13.0	
100N Gr. II	*Base Oil*	67.5			
110N Gr. II+	*Base Oil*		67.5		
4 cSt Gr. III	*Base Oil*			67.5	
GL-5 Package	*EP Package*	4.0	4.0	4.0	*Tiarco Octopol 229 EP, requires ester*
4 cSt Adipate	*Ester*	15	15	15	*Diisodecyl Adipate (DIDA)*
FUNCTIONAL PD-620	*Gr. II PPD*	0.5	0.5		
FUNCTIONAL PD-630	*Gr. III PPD*			0.5	
KV100, cSt	*D445*	15.2	15.4	15.6	*13.5-18.5 for 90, 24.0-32.5 for 140*
Viscosity Index	*D2270*	172	192	195	
20hr KRL Viscosity, cSt	*CEC L-45-A-99*	Pass	Pass	Pass	*>13.5 for 90, >24.0 for 140*
BF Visc @ -40C, cP	*D2983*	71,200	59,300	42,900	*< 150,000 cP*

75W Notes

- No ester required with most GL-4/GL-5 automotive gear packages
  - Low treat (4wt%) packages may require 10-15wt% adipate ester

- EPO is compatible with mPAO and PB to reduce cost
  - Formulations closer to the BF viscosity limit (150K cP) trend lower cost

- V-731 tends to be better at making 75W-140's

- Greater shear stability allows for formulating lower viscosity
  - Less VM, better economics
  - Lower KV100 = lower KV40 and KV20, better fluid efficiency and BF visc

NSF H1 ISO 220+ Gear Oil w/ V-732

- V-732 in PAO6
- 1.1% GA-400 for 200kg EP weld load

Formula by wt%	*Role*	ISO 220	ISO 320	ISO 460	ISO 680	ISO 1000	ISO 1500	ISO 2200
FUNCTIONAL V-732	*VM*	21%	25%	30%	35%	40%	45%	50%
PAO 6	*Base Oil*	77.7%	73.7%	68.7%	63.7%	58.7%	53.7%	48.7%
FUNCTIONAL GA-400	*EP Package*	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%	1.1%
FUNCTIONAL DF-400	*Defoamer*	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Viscosity Index	*D2270*	180	183	188	194	201	208	218
wt% mPAO 100 for same viscosity	*VM*	60%	70%	80%	90%	98.7%	--	--

- Or make an industrial full synthetic using GA-614, 4wt% = 315 kg weld load

EAL Hydraulics w/ V-732

- Max treats for Ecolabel (pending) – 100% C / 100% D
  - 5wt% TLL/ALL, 15wt% Grease, 20wt% PLL

- Compatible in many biobased/synthetic esters and PAO

Formula by wt%	*Role*	ISO 46	ISO 68	ISO 100	ISO 150	ISO 220
FUNCTIONAL V-732	*VM*	2.9%	7.0%	11.1%	15.4%	19.4%
Canola Oil	*Base Oil*	94.7%	90.6%	86.5%	82.2%	78.2%
FUNCTIONAL HF-595	*HF Package*	2.2%	2.2%	2.2%	2.2%	2.2%
FUNCTIONAL DF-500	*Defoamer*	0.2%	0.2%	0.2%	0.2%	0.2%
Viscosity Index	*D2270*	220	218	217	218	219

Hydraulics **High Temp Chain Oils**

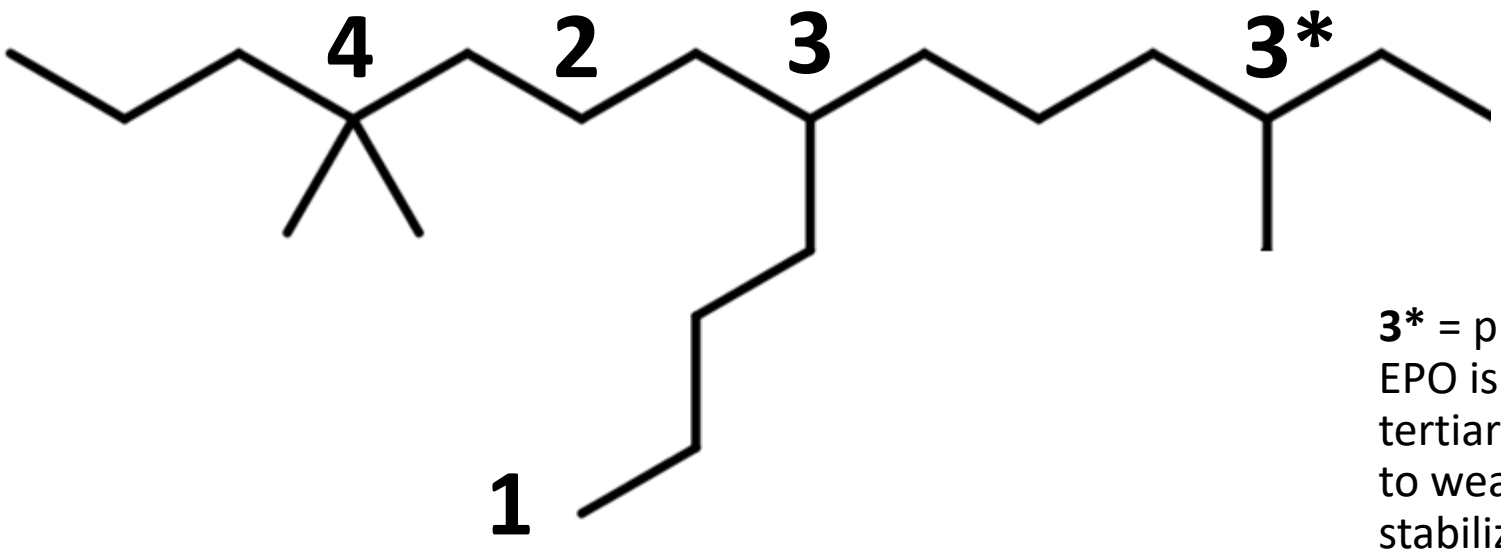
Biobased Grease

Summary

- FUNCTIONAL V-731 and V-732
  - New EPO entries to the FUNCTIONAL V-700 and HVSB lines
  - Exceptional shear stability, low temp fluidity, and thermal stability
  - Alternative or complimentary option to other offerings like PMA, V-705, or high viscosity base stocks
- Functional Products can assist in formulation design and testing

Chemical Stability of EPO vs. mPAO vs. PIB

- Four types of carbon sites from best to worst against radical attack at high T:
  - #4 – Tertiary alkane sites have no C-H bonds and only strong C-C, most resistant to radicals
  - #1 – Primary alkane sites have strongest C-H bonds, slow to break and form radicals
  - #2 – Secondary alkanes sites have weaker C-H bonds and can form radicals more easily
  - #3 – Tertiary alkanes have weakest C-H bonds and form radicals most easily



3* = propylene tertiary site on EPO is more stable than a PAO tertiary site, less "stuff" around to weaken C-H bond and stabilize radical formation

Master Organic Chemistry, "Bond Strengths And Radical Stability"

Hudzik JM, Bozzelli JW, Simmie JM. J Phys Chem A. 2014 Oct 9;118(40):9364-79.